2018

Stormwater Capture in the Built Watershed: Fostering Public Awareness of Water Conservation Through a Parcel-level Approach to Stormwater Management

Benjamin Rigby

Stormwater Capture in the Built Watershed: Fostering Public Awareness of Water Conservation Through a Parcel-level Approach to Stormwater Management

Benjamin Rigby

In partial fulfillment of a Bachelor of Arts Degree in
Environmental Policy/Organizational Studies

April 2018
Pitzer College
Claremont, CA

Readers:
Dr. Brinda Sarathy
Dr. Susan Phillips

Acknowledgements

I owe my profound gratitude to: Professor Susan Phillips for helping develop critical thought and for pushing me every day throughout this process; Professor Brinda Sarathy for providing mentorship and for sparking my interest in California water resource issues; Professor Char Miller for being a source of continually inspiring ideas and for instilling in me a love for understanding water's role in shaping the West; Professor Lance Neckar for the conversations about swale design and phytoremediation in native plant species; Mr. Kleinrock for letting me work on a project for the Chino Basin Water Conservation District and for guiding me throughout it; Mr. Dick Zembal, Mr. Greg Woodside, and Mr. Andy Campbell for their insight and suggestions on local water management practices; Mr. Justin Nakano for directing me towards crucial data for the project; Aunt Idy and Uncle John for prompting to pursue a project with a local agency; and my family for their never-ending support.

Abstract

As California contends with climate change and more extreme cycles of drought and deluge, water management agencies and conservation groups are looking towards solutions to the decreasing reliability of imported water supplies. Stormwater has historically been perceived as a threat to development but when captured properly, it presents a resource that can augment local water supplies. Solutions to water supply issues in California have traditionally employed technical and centrally controlled methods for importing water, but there is a growing understanding that parcel-level capture through vegetated swales presents an opportunity for reducing the impact that development has on California's hydrology. Vegetated swales mimic nature's effectiveness in reducing runoff speeds, removing pollutants and increasing groundwater supplies. No less a piece of California's water infrastructure than canals and dams, these swales bring water infrastructure into the context of the California landscape. My report for the Chino Basin Water Conservation District analyzes the feasibility of installing vegetated swales in the Chino Basin region.

Table of Contents

Terminology

Acre-foot (AF): A unit of volume of water commonly used in the United States when referring to large bodies of water. One acre-foot equals 325,851 gallons and is enough water to cover an acre of land, or a football field, to a depth of one foot.

Best Management Practice (BMP): Refers to a practice, or combination of practices, that are designed to achieve sustainable groundwater management and have been determined to be technologically and economically effective, practicable, and based on best available science. (California Sustainable Groundwater Management Act, 2014)

Bioinfiltration: A pollution control technique that uses living material and biological processes to degrade pollutants.

Infiltration: The downward movement of water via absorption into the soil at the surface.

Low Impact Development (LID): An approach to stormwater management that utilizes natural rather than mechanical BMP features to clean and infiltrate runoff in urban areas.

Parcel-level: At the scale of a single piece of property.

Percolation: The process by which water in the ground moves further downward until it reaches groundwater.

Vegetated Swale: A linear channel, lined with rock and plants, designed to collect and reduce the speed of runoff, absorb pollutants, and allow filtered surface water to percolate.

Introduction

On January 23, 2017, one day before California's exceptional drought status was removed from all regions in the state for the first time in five years, one of the larger rainstorms of the season rolled through the foothills of the San Gabriel Mountains. Just a day before, in Professor Char Miller's Water in the West class, I was examining photos from the Honnold Mudd Library's Special Collections of the 1938 floods that inundated the Claremont Colleges. Several of these striking photos are included on page four. On March 27, 1938, hallways became torrents of water-laden mud. Aerial photos revealed the extent of the floodplain weaving out of the 27-square-mile catchment area between Mt. Baldy and the start of the floodplain. The radiating patterns left by the waters spoke for themselves; it was as if the mountain placed a stamp over the watershed to warn what was then three Claremont Colleges and several hundred acres of citrus groves of the power of the floodplain.

Figure 1. Mt Baldy (Mt. San Antonio), its floodplain, and the city of Claremont after the floods. (Loyd Cooper, March 27, 1938)

The Tongva heeded this warning and constructed their homes away from the path of the floodplain. Seasonal floodwaters nurtured the growth of riparian plants from which the Tongva sustained themselves; they harvested elderberry fruit for winter food stores, made sycamore bark tea to relieve sore throats, and picked currant berries which, when cured with meat, made pemmican—a delicious, jerky-like snack. For several thousand years, the Tongva lived in understanding of the benefits provided by this watershed, and the countless others woven into the foothills of the San Gabriels. Beginning in the 19th century, colonizers began encroaching on this floodplain, giving negative connotation to the term “flood.” No longer did a flood represent the replenishment of groundwater supplies from percolation through the porous, alluvial soils. A flood meant that human developments, those same ones encroaching on the floodplain itself, were at risk of destruction. That human lives now placed within the floodplain were at risk.

In 1956, the US Army Corps of Engineers completed the San Antonio Dam, one of many that hold back the flood waters of the San Gabriel Mountains. By holding back the power of floods, these dams fostered more floodplain development. In comparing figures two and seven, Pitzer College lies directly in what was a boulder-filled wash that broke westward from the main wash in 1938. This was the first of three breaks from the main wash during that flood. Current satellite imagery reveals that all creeks in the Chino Basin watershed are confined in the same manner: Cucamonga Creek, Day Creek, Lytle Creek, and Cajon Creek are all either checked by dams or confined to a space up to which development is allowed.

So there was no more perfect day than on January 23, 2017, for me to embark on a quest to follow firsthand the system of flood control and water distribution 80 years after those floods. I started at the San Antonio Dam and noticed a small lake forming at its base. With a capacity to hold back 11,000 AF of water, the dam prevents such flooding from happening again. The structural integrity of this 60-year-old earthen dam, and the many others constructed at the same time, remains a separate topic of concern.

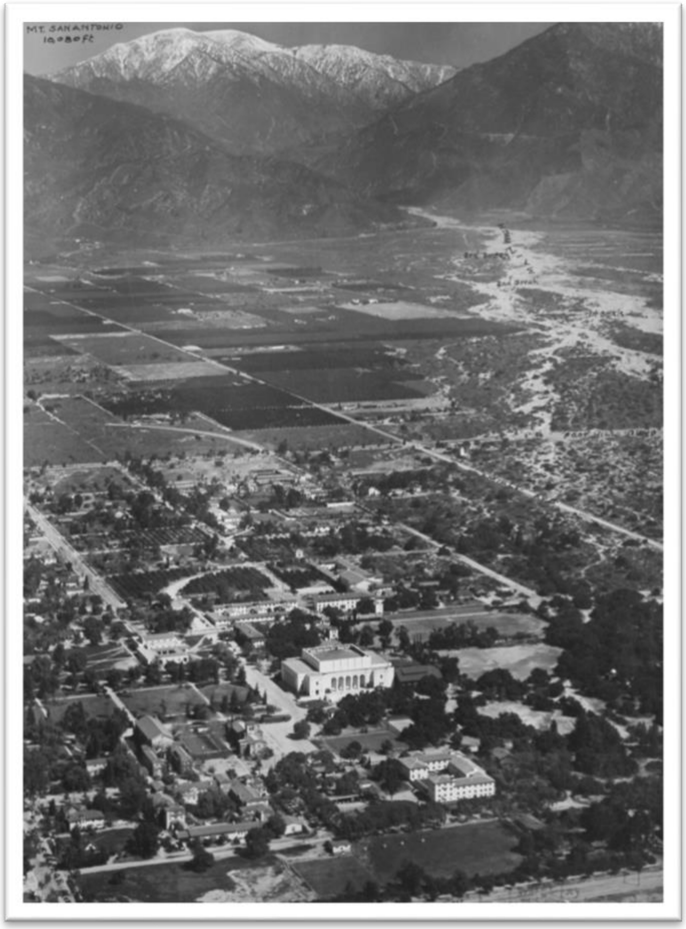


Figure 2. Pomona, Scripps, and Claremont Graduate University in the foreground. (Loyd Cooper, 1938)

Figure 3. Water rushes from Clark 3 Residence Hall, Pomona College. (Loyd Cooper, 1938)

Figure 4. An inundated courtyard in front of Frary Dining Hall, Pomona College. (Loyd Cooper, 1938)

Figure 5. A gouged College Avenue, south of Arrow Highway. (Loyd Cooper, 1938)

From the lookout near the dam, I could make out the Chino Basin under a blanket of dark clouds waiting to release another downpour. A concretized, fully lined channel runs 20 miles from this dam to Prado Dam at the southwest end of the basin. Dubbed the San Antonio Channel after the creek it paved over, it enabled flood control agencies to collect and dispose of stormwater—water from precipitation—in a controlled manner from over 37 square-miles of land below the dam. It also prevented all streamflow from percolating down into groundwater. The same thing happened to the other four creeks that weave into the Chino Basin from these mountains. This allowed development to edge closer to the floodplain, in turn producing more impervious cover from rooftops and asphalt, and subsequently more runoff.

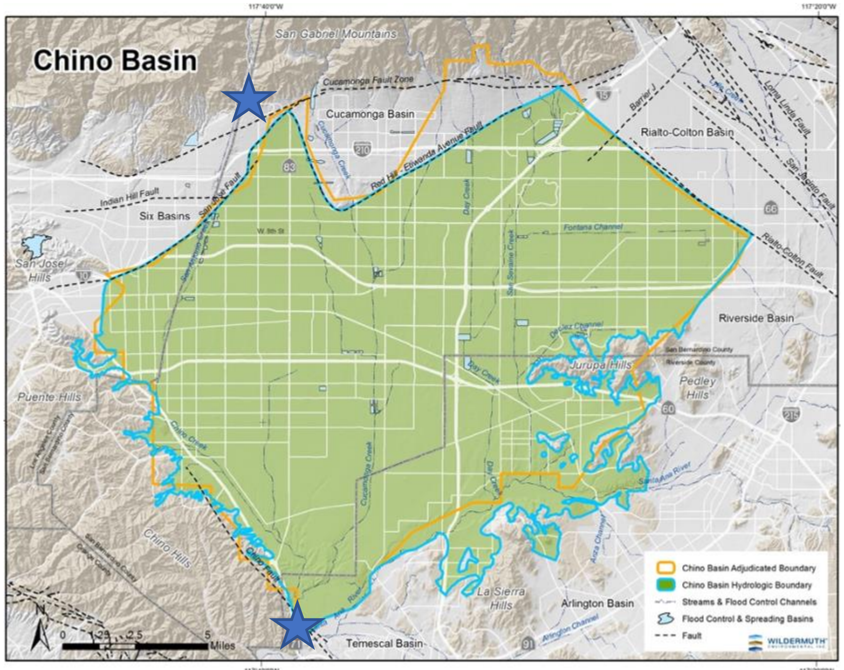


Figure 6. The Chino Basin covers 235 square miles of land within the Inland Empire. The upper star marks San Antonio Dam while the lower star marks Prado Dam. (2016 State of the Basin Report, Wildermuth Environmental Inc.)

In the dry autumn prior to this storm, I had seen the San Antonio Channel shimmering with clear water 6 inches deep; on this rainy day, I would find out why. I held a damp civil engineering map from the Metropolitan Water District, full of cryptic symbols and endless abbreviations. It detailed the entire distribution system for all of Southern California's imported water supplies. The only clue I began with was previous knowledge of the Rialto Feeder, a pipeline that brings in water from Lake Silverwood, 30 miles to the northeast. This reservoir is filled with water from 500 miles away via the California Aqueduct, a part of one of the largest water conveyance systems in the world that brings water from the northern part of the state. I finally found the intersection between the Rialto Feeder and the San Antonio Channel. It read "CB-59", which stands for a service connection to the Chino Basin Municipal Water District, one of a thousand such connections. I had the answer; this channel not only carries stormwater runoff and overflow from the dam, but also imported drinking water.

Another burst of rain fell through the clouds. I drove south on Mills Avenue to the Montclair Basins. These constructed cavities in the watershed enable water from this channel to percolate once more into Chino Basin's 5-million-acre-foot aquifer. This part of my journey ended back at Pitzer College, where I found fabricated streambeds, full of plants and gurgling water from gutter downspouts. Rooftops that shed water indeed represent a major source of impervious cover; but if we accept rainwater as a precious resource and appreciate rooftops as the miniature mountains they are, then we should in turn treat the landscape before them as a miniature floodplain.

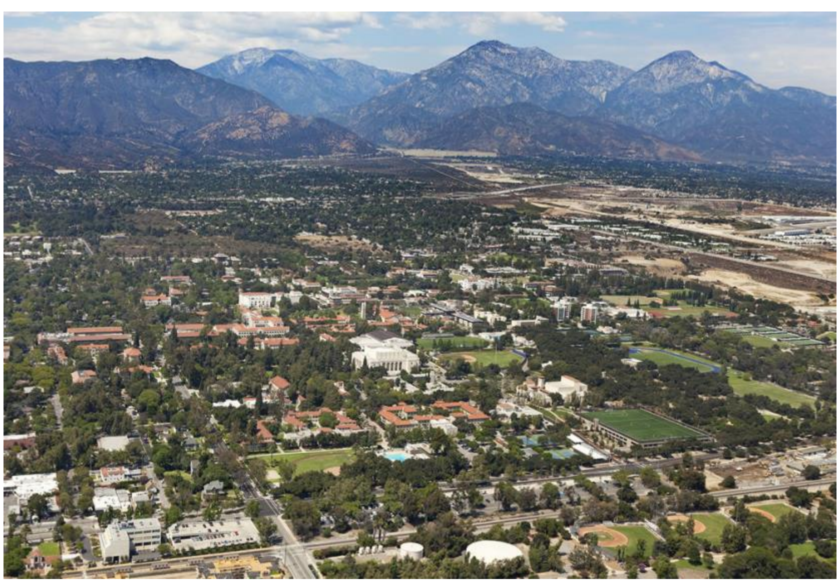


Figure 7. San Antonio Dam, visible at the mouth of the canyon to Mt. Baldy, allowed the development seen here to crowd out the floodplain. (hmc.edu, 2012)

These built streams, called vegetated swales in literature, represent a natural, small-scale approach to reducing the impervious surface cover of developed areas. People who are aware of the drawbacks of impervious surfaces, including decreased local water availability and increased quantities of polluted runoff, can participate in this deconstructive process of development. Those on developed land can work with the watershed to help restore the filtration and groundwater recharge processes that nature completes so effectively. Provided the means, those in this valley who understand that up to half of their household water comes from under their feet have the agency to live more consciously within the built watershed.

Water agencies in the Chino Basin are implementing stormwater capture plans to strengthen the region's resilience, which, in this context, is the ability of a simultaneously built and natural water system to adapt in the face of climate change and drought. Stormwater in this region is now viewed as a resource for recharging groundwater rather than a hazardous waste that threatens development. Currently, initiatives to capture stormwater in the Chino Basin are primarily large-scale, aiming to collect water from a defined region rather than from a single piece of property. As part of the trend of viewing stormwater as a resource, several Southern Californian cities are engaging with Low Impact Development (LID) initiatives to install natural, rather than mechanical, Best Management Practices (BMPs) that mimic nature's effectiveness in removing pollutants while increasing water supplies by capturing runoff at the source. One remarkably effective natural BMP is the vegetated swale. This elongated channel is unlined to allow infiltration and peak volume reduction, rock-filled to

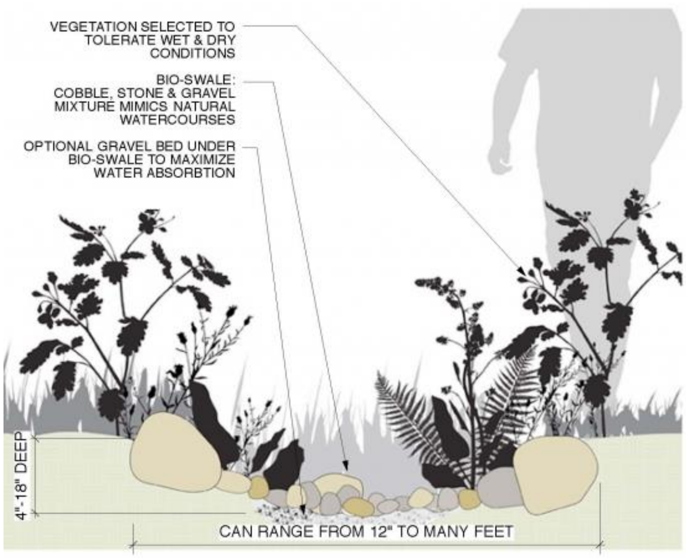


Figure 8. An illustrated schematic of a vegetated swale. (landscaperesource.com)

reduce runoff speed, and planted and mulched to facilitate pollutant capture. Vegetated swales are a popular parcel-level approach to stormwater capture because they can fit in narrow spaces alongside a street. Because these are incorporated into landscaping and building design, their presence is much more prominent to the passer-by than a conventional storm drain or percolation basin. Some installations use signs specifically intended to call attention to on-site runoff capture. In this way, low impact design can influence the public's perception towards recognizing stormwater as a resource.

The traditional technocratic and highly engineered approach to constructing and managing water infrastructure is no longer enough in an era of erratic weather and decreased rainfall. In short, a changing climate necessitates that Southern Californian's reorient their perceptions to view stormwater as a resource easily collected at the parcel-level. My work is part of a larger effort to bridge environmental literacy and public engagement to foster a more participatory approach to water management. Informed community members can act as stewards and expedite the spread of local knowledge about ways to utilize stormwater. This leads to a collective understanding of local water issues, their solutions, and a greater awareness of how communities can reduce their environmental footprint.

I begin this essay with a background explaining California's historical approach to managing both imported water and stormwater conveyance systems in response to a growing population. Recent climatic trends, the effects of which are exacerbated by development, pose another problem to the state, threatening the reliability of imported water supplies. This necessitates increased local water security and conservation through public outreach. In a fast-growing region, local water supply awareness is crucial to creating a cultural shift in Southern Californian's consumption of this resource. With a growing understanding throughout the state, and especially Southern California, that stormwater can be used to increase water supplies, vegetated swales provide one method of capture. My project, a report for the Chino Basin Water Conservation District (CBWCD), analyzes the best available sources of regional research to determine the feasibility of installing vegetated swales within the residential and business landscape. Two appendices included in the report provide educational material for CBWCD's website and annotated regional studies detailing the quantifiable strengths and limitations of using vegetated swales in the Chino Basin.

A Snapshot of Water Management in California

An understanding of California's traditionally technical approach to managing water helps clarify the relationship between this resource and the political power held by those who control its path. California's remarkably diverse landscapes include temperate rainforests in the northwest, the arid Sonoran and Colorado deserts in the south, and a 400-mile spine of granitic mountains in the middle—straddled in the west by the most productive agricultural region in the US and in the east by the hottest and driest place in North America. California's variable climate is marked on an annual basis by the variation in stream flows that range from less than 25 percent to over 200 percent of average as well as the historically dry period between May and November. This poses a challenge to state where 75 percent of its precipitation falls in the north, yet 75 percent of its water demand lies in the south (Hanak et al., 2011).

California was one of the most densely populated regions, with approximately 300,000 indigenous peoples inhabiting its land prior to settlement by the Spanish and Mexican governments in 1769 and 1821, respectively (Anderson, 2005). These settlers forced many Native Californians into labor to dig the wells and build the small dams used for domestic and irrigation purposes. In these settlements, which included pueblos, missions, and ranchos, only fields directly bordering natural water courses were irrigated. In 1848, following the period of Mexican settlement, the California Gold Rush skyrocketed settler populations. For the next 40 years, water management was uncoordinated among its users. Miners constructed over 6,000 miles of flumes to hydraulically extract gold while reclamation districts headed by merchants and landowners built ineffective levees in futile attempts to stop flooding on rivers (Hundley, 2001).

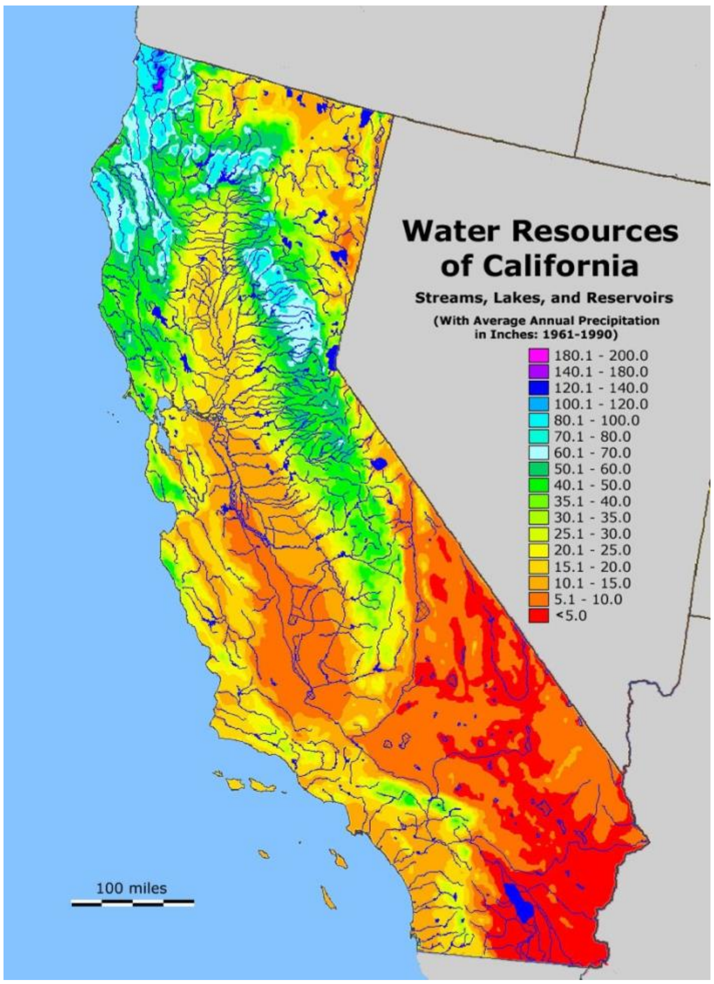


Figure 9. Average annual precipitation in California, recorded from 1961–1990. (geologycafe.com, modified from the USGS National Atlas)

With an economy shifting from gold mining to agriculture in the late 19th century, the state of California entered an "Era of Local Organization" in which the Wright Act of 1887 enabled farms and local municipalities to establish irrigation districts to construct the irrigation works required for farming the state's massive Central Valley (Hanak, et al., 2011). Funded through local bonds and property assessments, these districts moved water from local rivers to regional farms, in turn encouraging more farming. However, limited local water availability coupled with insufficient funding limited the scale at which these districts could construct water conveyance projects. The crisis of a booming population, 1.5 million by 1900, and a strengthening agricultural and commerce sector required a solution

California's entrance into the 20th century was marked by a rapid expansion in large-scale water conveyance infrastructure that worked to resolve the spatial disparity between water supply and demand. The expertise and sheer ability to build the pipelines, canals, and dams that redesigned the states natural hydrology defined this "Hydraulic Era" (Hanak et al., 2011). The rising political power of the irrigation districts that successfully established themselves encouraged the proliferation of water infrastructure. In 1920, the Imperial Irrigation District was gaining tremendous political power with over a half-million acres of arid, desert land turned green by the crops that could grow through the balmy winters. The capitalistic ventures of year-round, high-value agriculture, becoming competitive against other sectors in the nation, inherently shaped a top-down approach to managing irrigation projects such as the Colorado River Aqueduct, which brings water from 1000 miles away. Bringing agriculture to the forefront of a Western capitalist power required an elite class with "technical expertise and business acumen" to construct large-scale projects (Worster, 1982).

Figure 10. California's water infrastructure generally moves water from the wetter northern mountains to the drier southern region. (Public Policy Institute of California)

Here, the stakeholders of big infrastructure projects included the state and federal government, technocrats, and the ever-strengthening agriculture sector. Without the knowledge of how to build such projects, the individual citizen was left out.

To sustain the growing populations in the state's cities required a similar approach. With most of the state's booming population, 10 million by 1950, in the semi-arid south, and most of the precipitation in the Sierra Nevada mountains to the north, engineers launched a technocratic frenzy to construct the largest water conveyance system in the nation: 700 miles of concrete canals, 20 dams, and 13 million acre-feet of water storage to supply 26 million people and 750,000 acres of farmland (Hundley, 2001). In Southern California, approximately 30 percent of tap water is imported (mwdh2o.com). Consumers' ability to turn the faucet on and off at leisure without knowing whether their water comes from 500 miles away or several hundred feet underground creates a disconnect between the source and end use of water. This constructed system of water management not only lies behind technocratic institutions, but also behind the chain link fencing surrounding canals, dams and percolation basins. This, along with the "No Trespassing" signs limits liability and allows for more control over these municipality or government-owned systems, but also prevents the public from understanding the very systems that provide their ever-flowing daily water supply.

In the 20th century, a positive feedback loop began in California where development, edging closer and closer into floodplains, necessitated region-wide engineering efforts to control water from storms. As the counterpart to irrigation districts, local flood control districts made attempts to stop the floods that threatened expanding development, but these too proved futile in events such as the 1938 floods (Troxell, 1942). With the expertise to design new solutions and the capital to fund them, the U.S. Army Corps of Engineers intervened. Stormwater, and the flooding associated with it—which historically deposited the fertile soils that gave rise to the Chino Basin’s citrus industry—was considered a hazard. Its control allowed more development. In Southern California, this control materialized in the form of damming the creeks and canyon mouths that stood before the mountains. This helped reduce the peak volume of floods while concretized stream beds shunted this water to the ocean as fast as possible (Hanak et al., 2011). Much like the ability to turn a faucet on and off without knowledge of the water’s journey to the tap, the continual siphoning of stormwater and into constructed storm drains and tunnels further promoted an out of sight, out of mind mentality with this resource.

In a region limited by the whim of this very resource, it seemed only if clean water from afar was supplied and stormwater whisked away that the standard approach to development could thrive. The technical knowledge of experts in conjunction with state and federal dollars allowed for a controlled approach to simultaneously import a liquid treasure and dispose of a liquid threat. California’s 20th century response to a growing population and expanding economy solved the problem created by a geographic disparity between water supply and demand, but encouraged more development and only postponed the problems that a changing climate would bring to this system.

The Crises of Climate and Development

Attitudes towards water conservation and stormwater capture are shifting as climate change threatens not only imported but also local water supplies. The Intergovernmental Panel on Climate Change modeled in its 2014 Assessment Report that average and extreme temperatures in Southern California will continue to increase throughout the century (Pachauri et al., 2014). UCLA’s Climate Change in the Los Angeles Region Project predicts that average temperatures in the Inland Empire will increase in the coming decades more so than in coastal cities (Sun et al., 2015). A US Bureau of Reclamation study on the Santa Ana River Watershed modeled climate scenarios under several variables and estimated that the Chino Basin region will see significant decreases in snowpack, increases in flood severity and an overall reduction in natural recharge (Blickenstaff et al., 2013).

From 2011 to 2016, Southern California experienced some of the lowest amounts of precipitation in recorded history. During the 2017 winter, the same region experienced some of the highest amounts of precipitation per storm. This drought-deluge cycle is likely to worsen as climate change alters atmospheric patterns over the Pacific Ocean (Blickenstaff et al., 2013; Berg & Hall, 2015). Warming temperatures throughout the state are causing more precipitation to fall as rain rather than snow, leading to a reduction in the amount of snowpack storage from which Southern California draws a third of its water (Berg & Hall, 2017). This problem was highlighted in February 2017 when Oroville Dam's main and emergency spillways, part of the tallest dam in the country, nearly collapsed, causing 190,000 downstream residents to evacuate. Less snowpack in California's Sierra Nevada mountains poses serious concerns about the long-term viability of exporting this water to the drier part of the state. Southern California's other source of imported water comes from nearly a thousand miles away in the Rocky Mountains of Colorado. Within the Colorado River basin, declining snowpack and increased temperatures pose a similar threat. With the Colorado River already over-allocated among its water users—primarily agricultural industries and the cities that enjoy fresh vegetables year-round—there is more demand than supply. Within this current water accounting system, a year of average precipitation still results in Lake Mead, the largest reservoir along the Colorado, dropping 9 feet per year (Fleck, 2016).

The rate of urban development in Southern California, a direct outcome of the state's historic focus on importing water, has drastically reduced the ability of stormwater to recharge groundwater. When the San Antonio Dam was constructed in 1957, less than 10 percent of land was impervious urban cover while the rest was half agricultural and half undeveloped land. Now, over 60 percent of the Chino Basin is covered with impervious surfaces which prevent water from infiltrating into the ground (Wildermuth, 2016). Impervious surfaces create several problems that exacerbate the drought-deluge effects of climate change. With less of the ground acting as a sponge, which allows local precipitation to infiltrate at a rate of one foot per day, more water enters storm drains, bringing along trash that pollutes percolation basins. To avoid this, authorities at the Inland Empire Utilities Agency (IEUA) often wait during the first flush of rainfall before allowing stormwater to enter these basins. This moves the trash to the Santa Ana River and ultimately to the ocean where it is deposited on beaches. Somewhere along this route, maintenance crews paid by tax dollars are responsible for cleaning up trash. The opportunity cost here is the time spent picking up trash instead of completing other tasks. Since they shunt water anywhere but down, impervious surfaces create more flooding in poor draining areas, increasing traffic congestion when streets flood. Additionally, when bacteria levels in this water are high enough from combined storm-sewer overflows, public beaches are closed and entrance fee income is lost.

With more precipitation likely to fall as rain rather than snow at higher elevations, on-demand storage is more important than ever to collect as much rainwater for local supplies. Periods of drought followed by high volume storms sourced from atmospheric rivers of moist, tropical air further highlight the need for storage. Water stored in groundwater is also immune to evaporation that occurs on surface waters. With temperatures in the Inland Empire predicted to increase more than in coastal cities, reducing the urban heat island effect is crucial to human health (Hughes, Hall, & Kim, 2011). This effect occurs in regions that have large quantities of concrete and asphalt. These materials slowly absorb heat and release it after the sun sets, warming nighttime air which is then heated even more the following day.

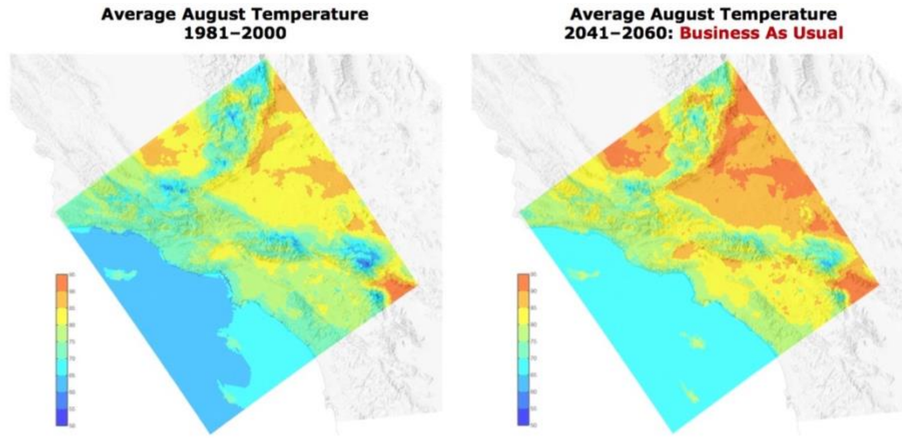


Figure 11. This spatial representation of average August temperatures shows that inland temperatures will likely increase more than coastal areas. (UCLA Climate Change in the Los Angeles Region Project)

Converting these impervious surfaces to natural cover increases albedo, which is the amount of heat from solar radiation that is reflected back into the atmosphere. This could be especially useful in the Inland Empire where the urban heat island effect amplifies the already-present long-term temperature increase.

In response to the crisis of climate, water agencies have been examining other previously unexamined supplies of local water. In 1994, the San Diego County Water Authority proposed a plan to remedy a growing demand and shrinking supply in a city that imported 90 percent of its water. While the authority recognized that treating its wastewater could provide a new water supply, much of the technical knowledge about the safety of blending treated wastewater with groundwater supplies was kept among panels of experts. When these experts explained the safety of the process to the public and the city council, incomplete and unclear information hindered their efforts. With a generally declining trust in public agencies at the time, the public largely claimed that the practice was unsafe and opposition groups adopted the “toilet-to-tap” slogan, eventually halting the project in 1999 (Hartley, 2006). Soon after, the Orange County Water District (OCWD), which provides water to 2.5 million residents within the southern Santa Ana

River watershed, began a highly transparent marketing campaign demonstrating the benefits, safety, and necessity of wastewater purification. In 2008, OCWD completed its Groundwater Replenishment System (GWRS). Public tours are available at this facility, which purifies 130 million gallons of wastewater per day, producing water so clean it exceeds state drinking water quality standards (Anthony et al., 2017). By turning a steady supply of waste which would normally be flushed to the ocean, into potable water, this innovative process presents one solution to securing local water supplies.

Wastewater purification, and educating the public of the benefits of doing so, demonstrates a shift in water management that recognizes the need for transforming a waste into a resource. Within this process, the technical approach ensures that water quality standards, among a myriad of other regulatory standards, are properly upheld. However, the approach of incorporating resilience, or the ability to adapt during times of drought, into the existing system of water management presents another solution less centralized in nature. There exists an opportunity to bring in other approaches to water management, specifically stormwater management, that are less technical in control.

A Shift Towards Resilience: Stormwater as a Resource

For the past two decades, agencies in the Chino Basin have recognized the benefits of viewing stormwater and dry-weather runoff as a resource for groundwater recharge. Since 2002, the IEUA begun its plan of building large-scale stormwater recharge facilities to reduce the volume of water sent to the Santa Ana River (RMPU, 2002). Prior to 2001, almost no runoff was recharged into the Chino Basin aquifer. From 2001-2005, recharge capacity increased to 6,000 acre-feet per year (AFY). From 2006-2015, recharge increased to approximately 10,600 AFY though during the drought much of this recharge was recycled wastewater (Wildermuth, 2013).

The 2001 Recharge Master Plan and the 2000 Optimal Basin Management Program, since updated, have served as a guide for monitoring and proposing centralized, large-scale recharge projects.

Water agencies in the Chino Basin are fortunate to sit atop a 5-million-acre-foot aquifer which provides storage that is especially useful in dry years when imported water supplies are restricted at the whim of up-state flows and snowpack. Traditionally fed by percolation from Santa Ana River and its tributary creeks, this aquifer is now managed in a hybrid system. Constructed basins accept stormwater runoff and imported water for percolation while injection wells place up to 30,000AFY of recycled, or treated wastewater, into the ground (IEUA, 2017). Approximately 460 production wells extract 145,000AFY of water from Chino Basin's aquifer. Currently, household water in the Chino Basin consists of 10 percent stormwater, 25 percent imported water, 30-40 percent groundwater, and about 30 percent recycled wastewater (IEUA, 2018). With the population of the Chino Basin expected to reach 1.6 million people by 2020, water demand is rising faster than imported supplies (Blickenstaff et al., 2013).

Much of the current literature surrounding water conservation, whether through stormwater capture or not, highlights a growing need for people and agencies to incorporate sustainable practices into daily routines, landscapes, and existing water management infrastructure. This ensures that the economic and social effects of the next drought or deluge cycle will be less detrimental than the last. Literature advocating stormwater capture in light of the need for resilience generally follows two themes: centralized and decentralized approaches. In the context of stormwater capture, the former refers to something such as a centrally controlled percolation basin whereas a decentralized approach implies a large quantity of distributed vegetated swales, or similar BMPs, within the same catchment area as a single basin.

This literature review serves to identify the means by which these different methods seek to achieve their goal and situates my project within the two approaches.

Centralized and Large-scale Approaches

Despite the ability of climate change to drastically alter California's hydrologic patterns, an impact assessment framework that both evaluates adaptation strategies and identifies tradeoffs between ecosystem services and the future impacts of climate change is largely absent in decision making processes (Purkey et al., 2006). Purkey (2006) created such a tool by bridging academia—specifically the quantitative assessment of climate change impacts to California's water system—with the policy making process. When considering climate change, system adaptability, and long-term population changes, Tanaka (2006) argues that California's water system is best fit to adapt through water transfers, technology adoption, and groundwater storage, though at a high cost. This study used an economic-engineering model approach to issues brought by climate change and it advocates solutions through large-scale approaches since these already work with existing infrastructure.

Within the Chino Basin region, water utilities operators such as the IEUA and Chino Basin Watermaster (CBWM) primarily advocate large-scale approaches to stormwater management since they provide a controlled and measurable way to move stormwater into groundwater (Wildermuth, 2016). For these agencies, two factors seem to guide their favor for large-scale approaches: cost-efficient economies of scale, and the ease of measuring and maintaining centralized projects. Only projects whose annualized recharge cost of stormwater is under $680 per acre-foot are considered (Wildermuth, 2013). This economic framework inherently limits their stormwater infrastructure choices to the largest and longest lasting devices. Centralized approaches to water management have their benefits for ensuring that the majority of water demand is met in a safe and measured manner that can be quantified and evaluated in regularly published reports.

Decentralized and Small-scale Approaches

Much of the scholarship on decentralized approaches reveals a range of ways in which community members can be the source of a reduction in water consumption. Renwick & Green (2000) used econometric modeling of residential demand side management and found that alternative instruments such as tiered water rate structures and public education campaigns were effective in reducing water demand among 7.1 million people in California. Here, consumers were the means through which water conservation took place. A report by the Pacific Institute indicated that 100 percent of California's urban water demand could be met through increased awareness of water efficient appliances, tiered rate structures and public education. While some argue that California will need to tap new sources of water in the future, this paper reveals that even with population growth, regional water needs can be met through methods such as water efficient residential landscapes that also function to capture stormwater, thus reducing the traditionally large quantities of water used in landscapes (Gleick et al., 2003).

Ambrose (2015) compared vegetated swales Australia and Southern California and noted that these small-scale devices are more expensive than their large-scale counterparts, but are an effective low-energy approach to cleaning and infiltrating stormwater. Garrison (2014) found that small-scale urban stormwater capture in Los Angeles and San Francisco could increase California's water supply nearly 200,000 acre-feet per year, and that large-scale capture through percolation basins could yield twice as much. A project for the Water Education Foundation completed by the 2013 Water Leaders Class brought together experts from various water management agencies in California and through interviews, found that one of the largest issues with stormwater management is a lack of public awareness about the detriments of runoff and the potential value of stormwater.

Linking Decentralized Approaches with Public Awareness

According to a 2016 survey by the Pew Research Center, 75 percent of Americans say they are particularly concerned about the environment as they go about their daily lives. While a smaller percentage say they will actively make an effort to help protect the environment, this statistic is still evidenced in a water conservation program by the Metropolitan Water District of Southern California. The district's 2016 advertising campaign results "underscored a strong willingness of many Southern Californians to permanently change their water use because it 'is the right thing to do' regardless of drought conditions" (Cole, 2018). Through public outreach on social media, billboards, print ads, and radio spots the district reported this conservation effort as the biggest factor in reducing residential water use during the 2016-2017 fiscal year. Bernedo (2014) studied the effects of a behavioral nudge aimed to create voluntary reductions in water use in Atlanta, Georgia during a drought and found that people continued using less water six years after the 4-month target period.

Public engagement and awareness is one of the most critical factors in fostering Southern California's ideological shift towards viewing stormwater as a resource. The Elmer Avenue Retrofit, a neighborhood-wide swale installation, hinged upon collaborative efforts between public utilities and residential property owners. For this project, the Los Angeles Council for Watershed Health and TreePeople embarked on a public outreach and education initiative to teach homeowners the benefits of this decentralized approach to stormwater capture. In a 2012 survey just after the retrofit was completed, 100 percent of community members along Elmer Avenue who responded agreed that rain falling on local homes could be captured and used to supply their community with water, versus 60 percent in 2006 (Belden et al., 2012). Bringing stormwater infrastructure into community landscapes also facilitates the spread of knowledge about the benefits of capturing stormwater as a method of conservation and recharge. In a separate survey of the same individuals, most respondents stated that they would consider purchasing a rain barrel if their neighbors had one and 80 percent felt that individuals can help reduce the amount of polluted runoff while adding to local water supplies (Bartrosouf, 2011). When agencies foster public awareness about conservation through capture at the source, rate-payers respond positively and reflect the behavior patterns of their community.

Detailed literature surrounding stormwater recharge is primarily technical in language and fails to be accessible to the public. In order to gain a comprehensive, highly detailed understanding of stormwater recharge in the Chino Basin, I needed to search through archives, read technical documents, and speak with experts at local water agencies. My report helps bridge the information shared between the public and water agencies by providing information in an accessible manner. In doing so, I hope to highlight two concepts:

1. Those educated or working in water conveyance systems need to understand how decentralized approaches to stormwater capture, at the responsibility of the agency and of the homeowner, can transform the water consumption culture of Southern California.
2. Educated homeowners engaging with their landscapes or water use patterns act as stewards and facilitate the spread of knowledge through interactions with their community.

To have an effectively informed public, a common understanding of technical and scientific findings is necessary. This gives informed residents agency to act as stewards and expedite the spread of local knowledge. This in turn leads to a collective understanding of local problems, their solutions, and a greater awareness of how residents can participate in a shift towards understanding the value of stormwater.

Vegetated Swales as a Method of Capture

A properly built vegetated swale combines several design elements that function to reduce all of the previously mentioned issues stemming from impervious surface cover. In 2012, Los Angeles signed in the Low Impact Development Ordinance which requires new and redevelopment projects to mitigate the effects of impervious surfaces by capturing stormwater runoff as close to its source as possible. Here, the responsibility to install natural BMPs that reduce runoff, such as the vegetated swale, rests upon the developer.

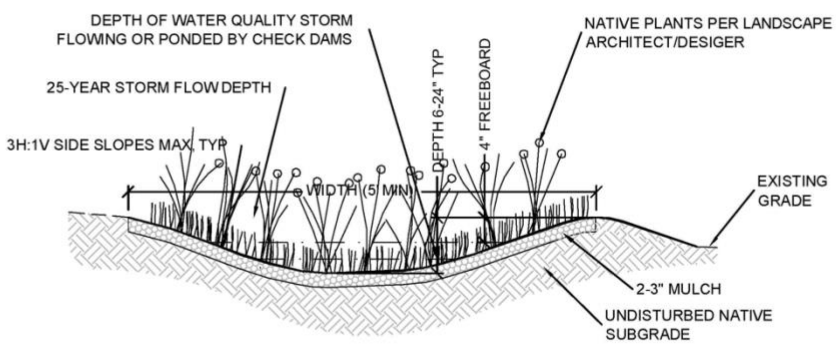


Figure 12. A peer-reviewed detail of a vegetated swale for planning purposes. (OSU Extension Service)

The use of vegetated swales in LID represents a way in which we can reverse the effects of impervious surfaces within the context of existing development. Detailed knowledge about the risks, costs, and benefits of swales primarily resides in several-hundred page documents full of data and written interpretation. Such documents are published by the LA Department of Public Works, City of LA, Caltrans, and the Council for Watershed Health and are cited in Appendix A of my report.

Also lacking is a region-wide initiative for installing parcel-level swales in the Chino Basin. Cities in the Chino Basin provide guidelines for implementing LID practices in development projects, but the specifications for swale’s filtration abilities and discussion of their strengths and limitations is not present. By providing an aggregate of regional studies from which conclusions can be drawn, my report provides the stepping point for CBWCD to begin an initiative to bring public awareness to local water infrastructure and to encourage community member participation in water conservation efforts.

The Project: Methodology and Findings

The Chino Basin Water Conservation District's mission consists of three goals: Demonstrate, Educate, and Percolate. Located in Montclair, CA, CBWCD has on-site demonstrations of water efficient landscapes, impervious surface conversions, and parcel-level stormwater capture devices. Serving 1.2 million residents from the cities of Montclair, Chino, Ontario, Upland, Rancho Cucamonga, and Chino Hills, they foster public stewardship through tours, landscaping classes, household irrigation evaluations, and on-site exhibits detailing where residents' water comes from. They also work with water utilities such as IEUA, CBWM, and several water districts to co-manage eight percolation basins which accept stormwater, recycled water, and imported water to recharge groundwater.

Through classes with Professor Brinda Sarathy of Pitzer and Professor Char Miller of Pomona, I toured CBWCD's campus and introduced myself to their Community Programs Manager. A year later, during my final spring at Pitzer, I was eager to work with a local water conservation agency and I asked if the district had any projects that I could help with. I was graciously referred to their Conservation Programs Manager, Mr. Kleinrock who told me of their latest desire to understand the effectiveness of implementing vegetated swales within CBWCD's service area. With public outreach rooted in their mission, CBWCD wanted to examine the possibility of vegetated swale use in the Chino Basin, where initiatives such as those in LA have not yet taken place. Always ready to expand CBWCD's scope of knowledge, Mr. Kleinrock expressed interest in the idea of a comprehensive report detailing the feasibility of swales, their strengths and limitations and an annotated compilation of all regional studies related to swales, should CBWCD decide to pursue an initiative similar to that of Los Angeles.

Methodology

From both coursework and my desire to read about regional water resource issues, I began this project with an existing base of knowledge and terminology. This helped me understand the language used by agencies and helped facilitate dialogue throughout my conversations with utilities' operators. It also helped with my research about, and initial understanding, of vegetated swales. Because the information on swales is distributed in various qualitative and quantitative formats by many different agencies, CBWCD wanted a meta-analysis of swale feasibility based on the best available information. A preliminary meeting with Mr. Kleinrock helped me understand the local stormwater infrastructure as well as the desired components of the report.

Much of the information I present in the report stems from reading upwards of 50 studies either directly and indirectly related to swale functionality. I sought out regional studies first because they consider Southern California's Mediterranean climate, stormwater infrastructure, and historical development among other region-specific factors. A summer internship with OCWD provided me with several contacts who are well versed in the technical understanding of groundwater recharge. One of several water sources for OCWD is the Santa Ana River, which collects excess drainage from the Chino Basin in San Bernardino County before passing through Prado Dam and weaving into Orange County. In phone calls with these individuals, I wanted to understand their view on vegetated swales as a decentralized approach to stormwater capture. I asked if there were groundwater contamination concerns, in what situations might vegetated swales ease problems that the district is facing, and what BMPs the district prefers most in regards to complying with municipal stormwater discharge permits. In addition to receiving links to the district's studies, I expanded my network by asking for contacts at other agencies.

I spoke with groundwater specialists at IEUA and CBWM to gather similar information. The latter's website contains a wealth of technical documents on groundwater levels, quantities of water extracted and recharged, and future plans for expanding water supplies through stormwater capture and wastewater recycling. Diving deep into technical documents is difficult work. Interpreting cryptic maps and hundreds of charts is a laborious process that often leaves me feeling as though I only need to dive deeper in order to uncover the answer I am searching for. Through detailed notes of the studies I read and conversations I engaged in, I started compiling and annotating a list of relevant studies per Mr. Kleinrock's request. I built the body of my report out of what I saw as a logical progression and engaging presentation of information.

The primary audience of my report includes members of CBWCD who are already familiar with the region's water resource and conservation needs. The secondary audience is for homeowners, to provide them access to condensed information in a digestible language through a list of frequently asked questions (FAQ). The delivery of this to the secondary audience will take place through the existing educational outreach means of CBWCD. Because there are potential limitations to swale use and due to time constraints, the report does not provide a service-area-wide plan for funding their installation. Rather, it serves as an informative guide and provides the initial momentum for an initiative on behalf of CBWCD to reduce and clean runoff at its source.

Findings

The report contains 10 sections as follows:

Introduction, Vegetated Swale Effectiveness in Southern California, Groundwater Contamination Potential, Maintenance Requirements, Capital and Long-term Costs, Current Stormwater Recharge in the Chino Basin, Fostering Resilience through Public Engagement, Possibilities for Installations, Appendix A: Annotated Studies, and Appendix B: Frequently Asked Questions.

The following section describes my general findings on the strengths and limitations of vegetated swales. I first needed to understand what vegetated swales do that makes them a popular LID option. They are one of about 13 BMPs that are regularly used and studied in Southern California. The others include bioretention, cisterns, dry ponds, wet ponds, dry wells, engineered wetlands, green roofs, infiltration basins, infiltration trenches, porous pavement, sand filters, and vegetated buffers.

Several major local studies show that a properly built vegetated swale is remarkably effective at capturing pollutants carried by stormwater runoff from streets and parking lots. The primary pollutants in local stormwater are heavy metals, organics, and nutrients. Heavy metals are removed by the soil in two processes: sediment filtration and adsorption to soil particles. According to data from reports, heavy metals are almost entirely captured by the first few feet of soil (Weiss et al., 2008; CWH, 2005). Organic pollutants such as petroleum and oil are filtered by mulch and organic matter. The majority of studies, local and international, show consistent results in the ability of vegetated swales to immobilize pollutants. Local studies mostly measure pollutant quantities in stormwater before and after it passes the length of a swale, revealing that rock, soil, mulch, and plants reduce the concentration of pollutants by about 60-80 percent (Caltrans BMP Pilot Program, 2008; Geosyntec, 2012; Belden, 2012).

As utilities discover the benefits of swales, they are also studying potential limitations, leaving some room for debate in the overall potential effectiveness of swales. With 40 percent of local water supplies coming from groundwater, the potential for contamination by these pollutants represents a public health issue. Soil's ability to capture contaminants within its pores in turn presents one of the more uncertain concerns about the safety and longevity of swales. Depending on the porosity of soils at the site, heavy metals could saturate the soil over time, eliminating its filtration capacity. This could lead to both heavily polluted top soil and pollutant leeching into groundwater, though neither have been comprehensively documented in parcel-level vegetated swales. A study by Davis (2003) examined soil filtration capacity of zinc, copper, cadmium, and lead and found nearly 100 percent removal rates under low pollutant load conditions. However, the study also estimated that over 15 years these same metals, which do not biodegrade, could accumulate in soil to levels exceeding those permitted by the EPA. A stormwater assessment report by the University of Minnesota titled reviewed nearly 90 studies on the topic. Most of the studies reported that pollutants were immobilized well within the first few feet of soil. Most of the concern was centered upon the potential need for replacing the first foot of soil after a decade of receiving stormwater runoff (NAP, 2016). This places an upper limit on the longevity of swales, perhaps less than the 25-year span designated in most reports. The need for site-specific research on soil filtration capacity, along with the public health concern of contamination eliminate my ability to definitively advocate for their installation alongside streets where standard vehicle traffic deposits heavy metals.

Vegetated swales have four other concerns that limit their potential longevity or call for regular maintenance: sedimentation, trash accumulation, weed growth, and vector control. Sediment consisting of silt and even smaller clay particles in great enough quantities is very impervious to water. Silt and clay can fill soil pores enough to reduce infiltration rates to zero. The Montclair percolation basins require sediment removal at least once a year, although there are proposals to increase this to twice a year to keep infiltration rates higher. OCWD stated that for their basins, infiltration rates are effectively nonexistent when a quarter of an inch of silt builds up. For vegetated swales, sediment deposition is a factor of the drainage area a swale is sited in and the length of time without rain. The Los Angeles LID Manual suggests a max drainage area of 5 acres per swale for this reason, although this is subject to the land use patterns of that area. Most swale installations lack a formal mechanism for trash removal and weed control. To remedy this, the Council for Watershed Health provided maintenance manuals and lessons to teach residents how to identify weeds, replace dead plants and establish new ones, and why trash removal is critical for keeping waterways clear.

Swales that replace a previously impervious concrete or asphalt surface increase albedo. This could be especially useful in the Inland Empire where onshore breezes and inversion layers during the summer amplify the heat island effect by trapping warm air (Stocker et al., 2013; Blickenstaff et al., 2013). Swales are also effective in reducing the speed of runoff, sequestering atmospheric carbon, creating habitat connectivity and providing aesthetic landscape value (Belden et al., 2012).

From a funding perspective, vegetated swales are not currently economically feasible when paid for by a single agency. This is due to two factors: the modest price of imported water compared to the amount captured by a vegetated swale during an average rain event, and the existing maintenance knowledge of large-scale percolation basins. This is subject to change in the future as these projects' costs relative to the cost of imported water and large-scale recharge decrease. Parcel-level swales in residential landscapes could take a decade before their cost of installation equals the value of water infiltrated. The maintenance requirements detailed in the previous section are also important to note when considering the cost of installation. Where a single agency is responsible for maintaining swales, costs of labor must be considered.

While small-scale vegetated swales are currently too costly for an agency to fund, and while potential maintenance and longevity limitations exist, there is still a need for residents to understand their role in the built watershed. Properly implemented and maintained, vegetated swales could serve this educational function while reducing onsite runoff and all of the other detriments of impervious surfaces. Every property functions as a watershed. Sourced from rain, water collects on rooftops, follows the path of least resistance to the ground, and enters the storm drain. After this point, the water itself and the pollutants it collects are out of sight and out of mind. For property owners already interested in re-landscaping, swales could provide not only added beauty, but also a means of on-site capture—a landscape version of the rain barrel.

An effective approach to initiating a cultural change towards water conservation while avoiding the uncertainties of vegetated swales is still possible through the use of these devices. The uncertainties of pollutant accumulation and groundwater contamination potential are rooted in studies capturing water from the street, where pollutant levels are much higher than an average residential property. The National Academies Press study on the risks, costs, and benefits of stormwater infiltration states that to avoid these concerns, swales should be sourced in areas with the least contaminated runoff (NAP, 2016). It then lists roofs, walkways, and little used driveways as possibilities for collection areas. What rain barrels do not capture, vegetated swales could.

Public awareness of stormwater as a resource is crucial to helping community members understand that the water they drink is stored under their feet after it falls from the sky. While vegetated swales replicate a natural process, they are no less a part of the water conveyance infrastructure than pipelines, canals, and percolation basins. They just lack a chain link fence around them. Citing swales within the residential, business, or park landscape calls attention to their purpose, much like a rain barrel, and brings the topic of water conservation to the passer-by. The vegetated swale could be a tool through which CBWCD educates residents about the private and social benefits of local runoff capture. In their outreach program, CBWCD already includes garden-planning services, irrigation assessments, and landscape evaluations; and their demonstration garden includes several examples of swale design. Throughout the landscape design appointments, vegetated swales could serve as a talking point for reducing both runoff volume and monthly watering bills. A list of frequently asked questions posted on the CBWCD website makes this knowledge of vegetated swales more accessible to the public. These are provided for use at CBWCD's discretion in Appendix B of the report.

When used to capture runoff from rooftops, patios, and driveways, parcel-level vegetated swales avoid the uncertainties of pollutant accumulation from streets, reduce runoff, and reduce the cost of outdoor watering. They can be easily integrated into residential and business landscapes. Increasing their presence could further advance public awareness that water conservation can easily be incorporated into daily life while providing both individual and community-wide benefits. As California's increasingly erratic climate swings from drought to deluge, and as increasing temperatures reduce the snowpack storage from which imported water comes, parcel-level could fulfil one component of the shift towards resilience.

Conclusion

This history of development in California is most notably marked by eras of water management that respond to crises of water supply. Now, the growing crisis of climate change, coupled with development, poses another threat where the cost of inaction far outweighs the cost of adapting. The solution to this is not explicitly rooted in technical and often-centralized projects nor is it solely rooted in decentralized stormwater capture. Indeed, centrally controlled treatment facilities and regional percolation basins provide consistent and measurable approaches to augmenting local water supplies. As shown by wastewater purification facilities, there is still a need for highly engineered approaches managed by those with the expertise and resources to maintain regulatory standards. However, the concept of treating individual properties as miniature watersheds that can infiltrate stormwater on-site can work in conjunction with these approaches. While more localized research is needed, parcel-level capture provides a way to restore the natural and beneficial processes to sites where development has paved over the floodplain.

As one method of this, vegetated swales bring stormwater infrastructure out from behind the chain link fence and into the California landscape. By bringing the concept of water capture into a location more prominent to the passer-by—whether alongside streets, parkways, or residential and commercial landscapes—swales can become a focal point for a changing ideology behind stormwater. Historically ingrained in the California Dream was the desire to create life where it would not otherwise exist. Lush landscaping and expansive lawns have consumed far more water than average annual rainfall allows for, yet when rain did fall, it was cast off as a nuisance and corralled into storm drains. Properties that capture, rather than cast off rain through their landscape are emblematic of a changing California Dream. In the face of longer droughts punctuated by more extreme precipitation, this version of the California Dream fosters life through a different means. In addition to sustaining native plants and wildlife, it contributes to an increasingly important role in directing the public towards understanding that stormwater capture in the built watershed brings environmental, personal and community-wide benefits. Sustainably managed, locally capture water supplies ensure that future generations can enjoy water security amid a changing climate.

References

Ambrose, R. F., & Winfrey, B. K. (2015). Comparison of stormwater biofiltration systems in Southeast Australia and Southern California. *Wiley Interdisciplinary Reviews: Water*, *2*(2), 131–146. https://doi.org/10.1002/wat2.1064

Anderson, B. G., & Bell, M. L. (2009). Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. *Epidemiology (Cambridge, Mass.)*, *20*(2), 205–213. https://doi.org/10.1097/EDE.0b013e318190ee08

Anderson, M. K. (2005). Tending the Wild: North American Knowledge and the Management of California's Natural Resources. Berkeley, CA: University of California Press.

Angeles, L., San, G., Rivers, & Council. (2010). Elmer Avenue Maintenance Manual. Retrieved from https://docs.wixstatic.com/ugd/ceb944_69b595c72b9f412b9aa0449798739375.pdf

Anthony, P. L., Bilodeau, D. R., Dewane, P. E. S., Green, C., Nguyen, D., Vicente, E., … General Manager, P. E. (2017). Engineer's Report on Groundwater Conditions, Water Supply and Basin Utilization in the Orange County Water District. Retrieved from https://www.ocwd.com/media/5395/2015-2016-engineers-report.pdf

Belden, E., Antos, M., Morris, K., & Steele, N. L. C. (2012). *Sustainable Infrastructure: The Elmer Avenue Neighborhood Retrofit*. Retrieved from http://lasgrwc2.org/Files/document/793_2012 Belden.pdf

Berg, N., & Hall, A. (2017). Anthropogenic warming impacts on California snowpack during drought. *Geophysical Research Letters*, *44*(5), 2511–2518. https://doi.org/10.1002/2016GL072104

Berg, N., & Hall, A. (2015). Increased Interannual Precipitation Extremes over California under Climate Change. *Journal of Climate*, *28*(16), 6324–6334. https://doi.org/10.1175/JCLI-D-14-00624.1

Bernedo, M., Ferraro, P. J., & Price, M. (2014). The Persistent Impacts of Norm-Based Messaging and Their Implications for Water Conservation. *Journal of Consumer Policy*, *37*(3), 437–452. https://doi.org/10.1007/s10603-014-9266-0

Bindoff, N. L., Bindoff, N. L., Willebrand, J., Artale, V., Cazenave, A., Gregory, J., … Shum, C. K. (2007). Observations: Oceanic Climate Change and Sea Level Observations: Oceanic Climate Change and Sea Level Chapter 5. *Climate Change*. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter5.pdf

California Department of Transportation. (2004). *BMP Retrofit Pilot Program*. Sacramento. https://doi.org/CTSW-RT-01-050

California Department of Transportation. (2011). *Biofiltration Swale Design Guidance*. Retrieved from http://dot.ca.gov/hq/LandArch/ec/stormwater/guidance/DG-Biofiltration Swale-060111.pdf

Chau, H.-F. (2009). *Green Infrastructure for Los Angeles: Addressing Urban Runoff and Water Supply Through Low Impact Development*. Retrieved from http://www.environmentla.org/pdf/LID-Paper_4-1-09_530pm.pdf

Chino Basin Water Conservation District. (2016). Annual Report, 55. Retrieved from https://www.cbwcd.org/ArchiveCenter/ViewFile/Item/119

Chino Basin Watermaster. (2013). Section 4 − Inventory of Existing Recharge Facilities and Their Capabilities. Retrieved from http://www.cbwm.org/FTP/Recharge Investigations and Projects Committee (RIPCom)/CB RMPU Steering Committee/2013 RMPUA/RMPU Sections/Red line Sections 1-4/20130903 Rechage Master Plan - Section4.pdf

Council for Watershed Health, Geosyntec Consultants, & Santa Monica Bay Restoration Commission. (2012). *Stormwater Recharge Feasibility and Pilot Project Development Study*. Retrieved from http://lasgrwc2.org/Files/document/785_1208020_SWRechargeFeasibility and PPDS_FinalReport.pdf

Dewoody, A., Cutter, W. B., & Crohn, D. (2006). *Costs and Infiltration Benefits of the Watershed Augmentation Study Sites*. Retrieved from http://lasgrwc2.org/Files/document/271_UCR_LASGRWC_041806.pdf

Gleick, P. H., Haasz, D., Henges-Jeck, C., Srinivasan, V., Wolff, G., Cushing, K. K., & Mann, A. (2003). Waste Not, Want Not: The Potential for Urban Water Conservation in California. Retrieved from https://www.colorado.edu/geography/class_homepages/geog_4501_sum14/Western Water/J.June 17/Gleick_waste_not_want_not_full_report.pdf

Hanak, E., Lund, J., Dinar, A., Gray, B., Howitt, R., Mount, J., … Thompson, ". (n.d.). Managing California's Water. Retrieved from http://www.ppic.org/content/pubs/report/R_211EHR.pdf

Hartley, T. W. (2006). Public perception and participation in water reuse. *Desalination, 187*, 115–126. https://doi.org/10.1016/j.desal.2005.04.072

Hughes, M., Hall, A., & Kim, J. (2011). Human-induced changes in wind, temperature and relative humidity during Santa Ana events. *Climatic Change, 109*(S1), 119–132. https://doi.org/10.1007/s10584-011-0300-9

Inland Empire Utilities Agency. (2015). Annual Water Use Efficiency Programs Report, 479. Retrieved from https://18x37n2ovtbb3434n48jhbs1-wpengine.netdna-ssl.com/wp-content/uploads/2016/12/FINAL-REPORT-FY15-16-lowres2.pdf

Landscape Performance Series. (2011). *Elmer Avenue Neighborhood Retrofit—Los Angeles, CA Methodology for Landscape Performance Benefits*. Los Angeles. Retrieved from http://watershedhealth.org/dataandreference/Document.aspx

Los Angeles & San Gabriel Rivers Watershed Council. (2010). Elmer Avenue Maintenance Manual. Retrieved from https://docs.wixstatic.com/ugd/ceb944_69b595c72b9f412b9aa0449798739375.pdf

Los Angeles and San Gabriel Rivers Watershed Council. (2005). Los Angeles Basin Water Augmentation Study Phase II Final Report. Retrieved from http://lasgrwc2.org/Files/document/265_2005_WAS Phase II Final Report_2005.pdf

Marks, M., Ramakrishnan, K., Cioffi, J., Fairris, D., Green, P., Esterling, K., … Lee, J. G. (2008). Policy Matters: Capturing Urban Stormwater Runoff: A Decentralized Market-Based Alternative, *2*(3). Retrieved from http://policymatters.ucr.edu/pmatters-vol2-3-water.pdf

Making Water Conservation a California Way of Life. (2017). Retrieved from https://www.water.ca.gov/LegacyFiles/wateruseefficiency/conservation/docs/20170407_EO_B-37-16_Final_Report.pdf

National Academies of Sciences, Engineering, and M. (2016). *Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits*. Washington, D.C.: National Academies Press. https://doi.org/10.17226/21866

Noah Garrison. (2014). Stormwater Capture Potential in Urban and Suburban California. *Pacific Institute*. Retrieved from https://www.pacinst.org/wp-content/uploads/2014/06/ca-water-stormwater.pdf

Pachauri, R. K., Meyer, L., Van Ypersele, J.-P., Brinkman, S., Van Kesteren, L., Leprince-Ringuet, N., & Van Boxmeer, F. (n.d.). Climate Change 2014 Synthesis Report The Core Writing Team Core Writing Team Technical Support Unit for the Synthesis Report. *Russian Federation), Hoesung Lee (Republic of Korea) Scott B. Power (Australia) N.H. Ravindranath (India)*. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf

Perrone, D., & Merri Rohde, M. (2001). Benefits and Economic Costs of Managed Aquifer Recharge in California. *San Francisco Estuary and Watershed Science*, *14*(2).

Purkey, D. R., Huber-Lee, A., Yates, D. N., Hanemann, M., & Herrod-Julius, S. (2006). Integrating a Climate Change Assessment Tool into Stakeholder-Driven Water

Management Decision-Making Processes in California. *Water Resources Management*, *21*(1), 315–329. https://doi.org/10.1007/s11269-006-9055-x

Renwick, M. E., & Green, R. D. (2000). Do Residential Water Demand Side Management Policies Measure Up? An Analysis of Eight California Water Agencies. *Journal of Environmental Economics and Management*, *40*(1), 37–55. https://doi.org/10.1006/JEEM.1999.1102

Sun, F., Walton, D. B., Hall, A. (2015). A Hybrid Dynamical–Statistical Downscaling Technique. Part II: End-of-Century Warming Projections Predict a New Climate State in the Los Angeles Region. *Journal of Climate*, *28*(12), 4618–4636. https://doi.org/10.1175/JCLI-D-14-00197.1

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., … Chen, H. (2010). The urban heat island and its impact on heat waves and human health in Shanghai. *International Journal of Biometeorology*, *54*(1), 75–84. https://doi.org/10.1007/s00484-009-0256-x

Tanaka, S. K., Zhu, T., Lund, J. R., Howitt, R. E., Jenkins, M. W., Pulido, M. A., … Ferreira, I. C. (2006). Climate Warming and Water Management Adaptation for California. *Climatic Change*, *76*(3–4), 361–387. https://doi.org/10.1007/s10584-006-9079-5

The Metropolitan Water District of Southern California. (2018). Achievements in Conservation, Recycling and Groundwater Recharge. *Water Tomorrow: Annual Report to the California State Legislature*. Retrieved from http://www.mwdh2o.com/PDF_About_Your_Water/2.1.1_Regional_Progress_ReportSB60.pdf

Weiss, P. T., Lefevre, G., & Gulliver, J. S. (2008). *Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices: A Literature Review*. Minneapolis, MN. Retrieved from https://www.pca.state.mn.us/sites/default/files/stormwater-r-weiss0608.pdf

Xiao, Q., Gregory McPherson, E., Zhang, Q., Ge, X., & Dahlgren, R. (n.d.). Performance of Two Bioswales on Urban Runoff Management. https://doi.org/10.3390/infrastructures2040012

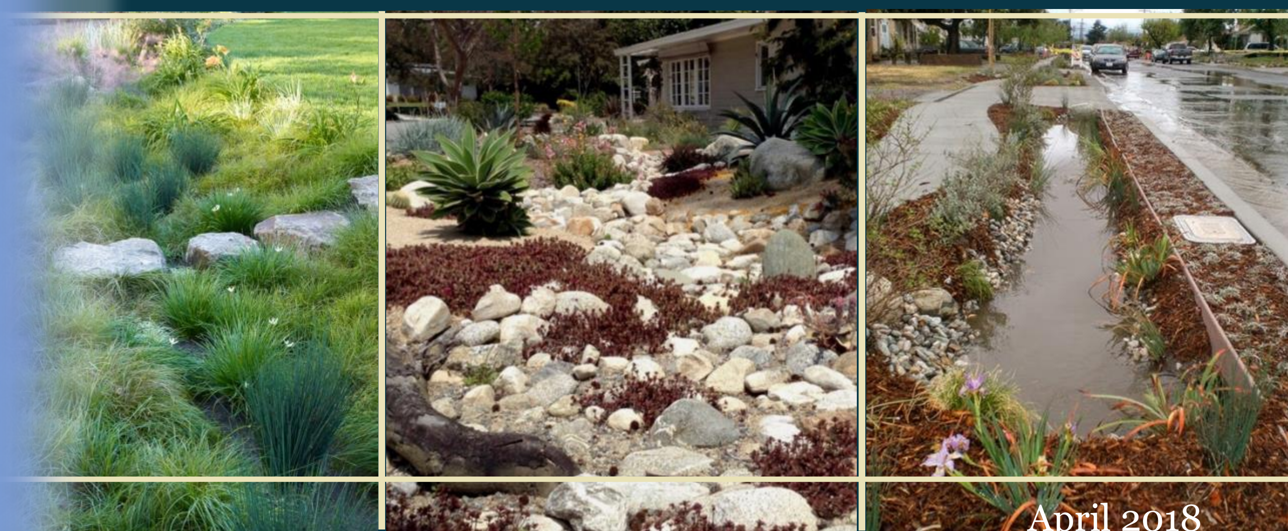
USBR. (2013). Climate Change Analysis for the Santa Ana River Watershed Santa Ana Watershed Basin Study, California Lower Colorado Region. (2013). Retrieved from https://www.usbr.gov/lc/socal/basinstudies/OWOWReferences/FinalReport/TM 1 Climate Change.pdf

Wildermuth. (2016) Chino Basin Watermaster: 2016 State of the Basin Report. Retrieved from https://cwc.ca.gov/WISPDocs/IEUA_2016 State of the Basin Report.pdf

Appendix A: *A Feasibility Report on Parcel-Level Vegetated Swale Installation in the Chino Basin*

Stormwater Capture in the Built Watershed

A Feasibility Report on Parcel-level Vegetated Swale Installation in the Chino Basin



April 2018

Prepared for

Chino Basin Water Conservation District

By
Benjamin Rigby
Pitzer College

Executive Summary

In response to California's changing climate, water supply and flood control agencies are paying more attention to the benefits of replicating natural hydrologic systems to manage stormwater as a resource. This approach is known as Low Impact Development (LID). It intentionally employs natural Best Management Practices (BMPs) that mimic nature's effectiveness in removing pollutants while increasing groundwater supplies.

One remarkably effective natural BMP is the vegetated swale. This elongated channel is unlined to allow percolation and peak volume reduction, rock-filled to reduce runoff speed, and planted and mulched to facilitate pollutant capture. Vegetated swales are a popular small-scale approach to stormwater capture because unlike large-scale percolation basins, they fit in narrow spaces alongside a street. This report refers to small-scale swales as parcel-level swales because they are designed to capture the runoff from a single property.

While vegetated swales are popular in Los Angeles's LID program, their use is less studied in the Inland Empire's Chino Basin. There is some concern about the potential for groundwater contamination in swales that collect street runoff and there are uncertainties with their construction and maintenance costs. This report discusses regional studies and provides current findings on the benefits and limitations of installing vegetated swales in the Chino Basin.

A street-side swale with weirs slows down runoff in Paso Robles. (cannoncorp.us)

Cover photos from left to right: Marion Brenner, Jonescape Inc., Council for Watershed Health

Table of Contents

Introduction

Stormwater capture increases drought resiliency and independence from imported water supplies. With population growth and development, the Chino Basin's growing impervious surface area, now at 60% of land cover, results in greater quantities of polluted runoff. Thanks to growing awareness of stormwater as a local resource, runoff from the Chino Basin's 235 square miles now travels to a network of percolation basins. During large storms when excess water flows into the Santa Ana River and ultimately into the ocean, pollutant loads in runoff often cause temporary closure of public beaches. As cycles of drought and deluge become more volatile, Southern California will have to place more emphasis on local water security by collecting and cleaning locally sourced water. Vegetated swales may pose one solution to living more sustainably within the built watershed.

Los Angeles's 2012 Low Impact Development (LID) ordinance is the largest local example of a city-wide ordinance that requires new and redevelopment projects to mitigate the impacts of stormwater runoff as close to the source as possible. Any impervious surface can be a source of runoff. Since 2000, LA has been closely studying the feasibility of parcel-level stormwater recharge through its *Watershed Augmentation Study* (LAWAS) and for this reason is referenced throughout this report.

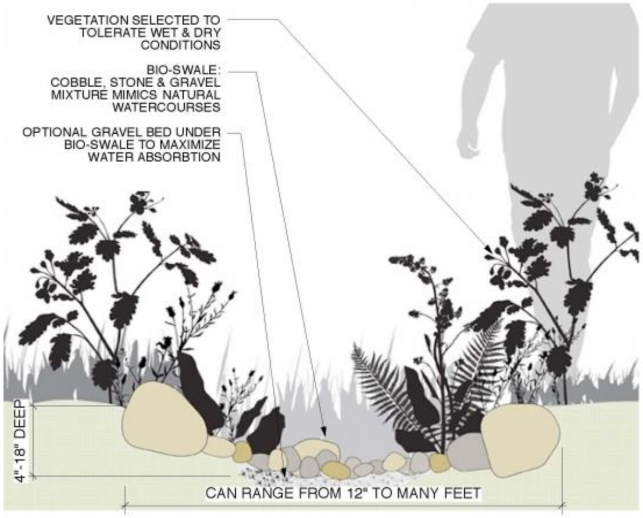


Figure 13. An illustrated schematic of a vegetated swale. (landscaperesource.com)

Although stormwater runoff from rooftops, parking lots, and streets can contain pollutants, when filtered it presents an increasingly popular source of water. Vegetated swales pose one way to capture and filter it. However, while research surrounding their design and use has grown significantly in the past decade, there remain some unstudied aspects. These are described in this report.

The *Green Infrastructure for Los Angeles Report*, *Los Angeles County LID Standards Manual*, and *Caltrans BMP Final Report* all provide similar definitions for a vegetated swale. While the following BMPs generally serve the same purpose, their distinctions are important to note in reference to the studies listed in Appendix A.

Vegetated swale – a broad shallow channel with a dense strand of vegetation covering the sides and bottom. These are designed convey water, trap pollutants and reduce runoff speed

Bioretention – the practice of using a shallow vegetated depression which removes pollutants and stores stormwater for infiltration over a short period before drying.

Bioswale – similar to a vegetated swale in planting and speed reduction, this system encourages water to spend more time pooled up, with less of an emphasis on conveyance

Infiltration swale – a swale designed to infiltrate stormwater with less of an emphasis on vegetation. It may be entirely covered with rock.

Stormwater Filtration

A properly built vegetated swale is remarkably effective at capturing pollutants carried by stormwater runoff from streets and parking lots. Sediment filtration and adsorption are the two primary physical methods of immobilizing heavy metals. During sediment filtration, particulate metals, which are bound to suspended solids, are captured in the pores of soil at the surface. Suspended solids are comprised of silt and clay, so soil porosity aids in sediment removal as well.

Common Stormwater Pollutants

HEAVY METALS

- Cadmium
- Chromium
- Copper
- Lead
- Nickel
- Zinc

ORGANICS

- Gasoline
- Hydrocarbons
- Oils

NUTRIENTS

- Nitrogen
- Phosphorus

OTHER

- Salts
- Pathogens

Particulate metals make up the majority of heavy metals found in stormwater, but a fraction exist as dissolved metal ions. These travel slightly further downward and are filtered through adsorption. During this process, they undergo cation exchange which binds them to soil particles. Soil type affects this as clay and organic matter allow for more cation exchange.

Studies show that organic petroleum and hydrocarbon pollutants from both combustion and atmospheric deposition are captured within the first few inches of mulch. Biodegradation of these is dependent upon the amount of microbe activity.

Phytoremediation is the process by which plants, with assistance from bacteria and fungi near their roots, uptake heavy metals and organic pollutants and assimilate them into their tissues. Research shows that in wetlands, certain species such as arroyo willow and bulrush are much more effective at this than others. Southern California's Mediterranean climate means that swales will be dry for several months in the year, potentially reducing the effectiveness of phytoremediation. More research is needed to determine if this process, as well as the biodegradation of organic pollutants, is as effective in dry soils where microbial activity is limited.

Local studies show consistent results in the filtration capacities of vegetated swales. The *Caltrans BMP Retrofit Pilot Program* studied six large-scale bioinfiltration swales in 2004 and compared the percentage pollutant content of water entering and exiting a swale. The percent concentration reductions of water exiting are shown in table 1.

Appendix A provides several other local studies that show similar results: *Santa Ana River Water Quality Health Study (2004), Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices (2008), Los Angeles Basin WAS Phase II Final Report (2005), Sustainable Infrastructure: The Elmer Avenue Neighborhood Retrofit (2012), Using Graywater and Stormwater to Enhance Local Water Supplies, An Assessment of Risks, Costs, and Benefits (2016)*

Table 1: Percent reduction in pollutants concentration of water exiting swales. TPH refers to Total Petroleum Hydrocarbons.

Pollutant	Percent Reduction
Total Suspended Solids	49%
Total Copper	63%
Total Lead	68%
Total Zinc	77%
Dissolved Copper	49%
Dissolved Lead	57%
Dissolved Zinc	74%
TPH Oil	51%
TPH Diesel	69%

Velocity Reduction

Vegetated swales dissipate the energy of runoff by simply slowing the current down. This occurs due to a swales' natural permeability but can be reinforced by installing rock or concrete check dams. In high volume channels or areas sloped greater than 5%, these check dams are especially recommended as vegetated swales lose effectiveness with increased flow velocity. For this reason, Ventura's permitting system does not allow residents to install swales on slopes 5% or greater.

Emissions Reduction and Carbon Sequestration

The Elmer Avenue Retrofit in Sun Valley, California is a demonstration project of the LAWAS aimed at assessing the feasibility of neighborhood-scale stormwater capture. Between April 2010 and December 2011, this project captured 23 acre-feet of stormwater in its underground infiltration galleries. These gravel beds are located underneath the street and receive swale water via a perforated pipe. The study calculated that every 10 acre-feet of locally recharged groundwater offsets 4.3 tons of carbon emissions from the energy used to import the same quantity of water. An estimated 7.25 tons of carbon was sequestered by soil and plant tissue during the first year of this project, although this is expected to decrease to 2 tons annually.

Habitat Connectivity and Beautification Value

The vegetation in a swale provides habitat for insects and lizards while blooming flowers attract nectar-sipping birds and butterflies. Native vegetation is more suited to the wet and dry cycles of Southern California's climate and a chart by Stopwaste provides native plant names and requirements. This increases the biological diversity of an urban landscape, while enriching the plant palette of a neighborhood. When maintained, vegetated swales add beauty and landscaping value, often serving as a non-irrigated and refreshing contrast to neglected parcels. This demonstrates to the public that the dream of beautiful landscaping and water conservation through stormwater capture can coexist.

Decreased Albedo

Albedo is the amount of heat from solar radiation that is reflected back into the atmosphere. Concrete or asphalt surfaces retain this heat and create an urban heat island effect. Converting these surfaces to natural cover increases albedo, which could be especially useful in the Inland Empire where onshore breezes and inversion layers during the summer amplify the heat island effect by trapping warm air. More on this can be found in the *Climate Change in the LA Region Project* and the *Climate Change Analysis for the Santa Ana River Watershed* report.

Figure 14. Stormwater entering a vegetated swale in the parkway on Elmer Avenue. (Council for Watershed Health)

City Initiatives for Street Capture

Recognizing the benefits of swales, cities such as Los Angeles and Ventura allow property owners to cut their curbs, enabling runoff from the gutter to pass through a vegetated swale before exiting at another curb cut. Los Angeles' LID program only requires such BMP devices on new and redevelopment projects, leaving out existing development. In Ventura, city engineers have created a standardized curb cut diagram for contractors to follow. Residents must provide a sketch of their plan and pay a $372 fee to obtain a curb cut permit.

Conclusion

Vegetated swales provide a wealth of benefits that utilize nature's efficiency to reduce the detrimental effects of impervious surface cover. Their ability to filter pollutants in a natural and energy-free manner makes them a popular option for reducing runoff, especially in smaller spaces. Depending on the needs and constraints of a specific site, swale construction can be tailored to produce the specific benefits desired. In high volume areas, larger rocks may be required to reduce the speed of runoff whereas in low volume areas or front yards, an emphasis on flowering vegetation may be desired.

Groundwater Contamination Potential

Soil's ability to capture contaminants within its pores in turn presents one of the more uncertain concerns about the safety and longevity of swales. Depending on the porosity of soils at the site, heavy metals could saturate the soil over time, eliminating its filtration capacity. This could lead to both heavily polluted top soil and pollutant leeching into groundwater, though neither have been comprehensively documented in parcel-level vegetated swales. A study by Davis et al. (2003) examined soil filtration capacity of zinc, copper, cadmium, and lead and found nearly 100% removal rates under low pollutant load conditions. However, the study also estimated that over 15 years these same metals, which do not biodegrade, could accumulate in soil to levels exceeding those permitted by the EPA.

The *LA County LID Standards Manual* requires that stormwater be fully treated if soil infiltration rates exceed 2.4 inches per hour, due to the risk of groundwater contamination. The same report states that infiltration should not take place where the water table is within 10 feet of the ground.

In the Chino Basin, groundwater levels are no higher than 50 feet below the surface at Prado, and increase to 500 feet below ground towards the northern portion. According to the CBWCD 2016-17 Annual Report, the 8 basins' average percolation rate is approximately 1 inch per hour. College Heights East Basin is the only one to exceed 2.4 inches per hour, with a rate of 3 inches per hour. Water entering these is typically diluted with imported water so pollutant accumulation in these specific basins is less of a concern, though these rates provide important information about local soil infiltration rates.

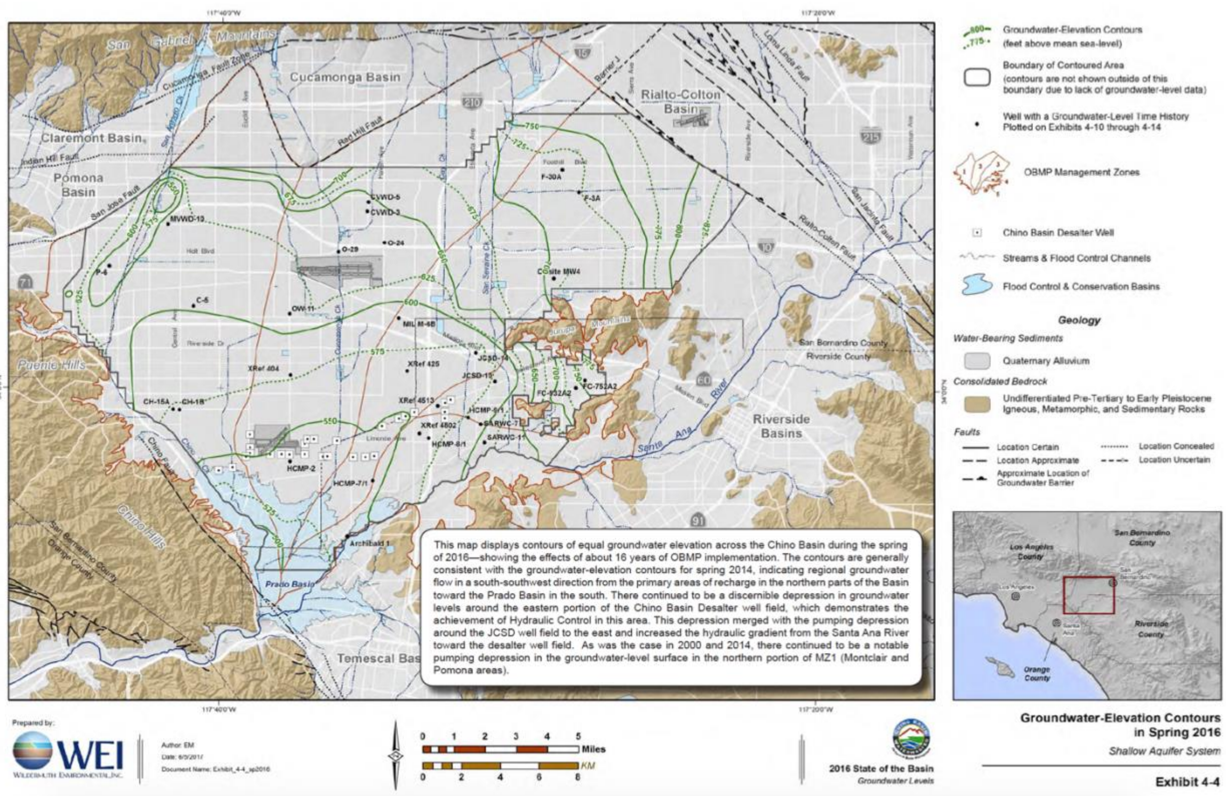


Figure 15. A groundwater elevation map of the Chino Basin. (2016 State of the Basin Report, Wildermuth Environmental Inc)

The stormwater assessment report, *Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices*, reviewed nearly 90 studies on the topic. Most of the studies reported that pollutants were immobilized well within the first few feet of soil. Much of the concern was centered upon the potential need for replacing the first foot of soil after a decade of receiving stormwater runoff.

The *LA Basin Phase II Final Report* from 2005 assessed groundwater quality impacts from then-recently installed stormwater infiltration BMPs and found that no immediate impacts exist. The Santa Ana River Water Quality Health Study used heavy metal tracers and found that heavy metal deposition from the river, which accepts stormwater runoff and treated wastewater, was below regulatory limits. The Chino Basin Stormwater Resources Plan of 2016 stated that stormwater infiltration increases water quality of the Santa Ana River by removing heavy metals although specific data for this was not cited.

Conclusion

The consensus of these studies generally suggests that infiltration BMPs are protective of groundwater supplies, given a deep enough aquifer and a percolation rate slower than 2.4 inches per hour. However, because contamination represents a public health issue, its potential occurrence necessitates local studies on pollutant travel. The studies cited in this paper suggest regular testing of infiltration sites. The accumulation of pollutants in topsoil in swales seems to be of greater concern than groundwater contamination since this is where most pollutants collect. This presents limitations on the life-span of vegetated swales.

Maintenance Requirements

Sedimentation

Sediment consisting of silt and even smaller clay particles in great enough quantities is very impervious to water. Silt and clay can fill soil pores enough to reduce infiltration rates to zero. Montclair percolation basins require sediment removal at least once a year, although there are proposals to increase this to twice a year to keep infiltration rates higher. The Orange County Water District stated that when their basins accumulate so much as a quarter of an inch of silt, infiltration is effectively nonexistent. For vegetated swales, the rate of sediment deposition is primarily a factor of the area of drainage a swale receives and the time without precipitation. The *LA County LID Standards Manual* suggests a max drainage area of 5 acres per swale for this reason, although this depends on the land use of the collection area.

Two years after the Elmer Avenue Retrofit, unexpected amounts of sediment build up was reported at the street inlets. At this site, sediment build up has not yet affected infiltration rates. This could be due to particularly porous soil or limited study time. Depending on soil type, drainage area, and quality of stormwater received, further research is necessary to fully understand the life span of vegetated swales regarding sedimentation.

Figure 16. Sediment accumulation shown in the foreground by the inlet from Elmer Avenue. (Council for Watershed Health)

Trash Accumulation

Vegetated swales studied by Caltrans lacked a formal mechanism for trash removal. At these sites and at the Elmer Avenue Retrofit, trash build up occurred although at the latter, it is removed by home owners participating in the retrofit program. A groundwater recharge coordinator at the Inland Empire Utilities Agency (IEUA) noted that during first flush rain events, significant amounts of trash enter the San Antonio Channel and subsequently the Montclair basins. Vegetated swales, if consistently maintained, could provide a means of trash control at the source. Those with a defined inlet could house a trash screen to make collection easier, provided they are regularly cleared of trash.

Weed Growth

Generally speaking, when a vegetated swale is properly landscaped, weeding is a low maintenance issue. While the *Caltrans BMP* study noted that vegetation management was one of the larger costs, but this study used grass which required mowing to maintain a six-inch height.

At least a three-inch layer of mulch should be added to suppress weeds. Because mulch decomposes over time, it should be topped off every year. Other general maintenance includes pruning shrubs and clearing accumulated debris. Residents along Elmer Avenue were provided lessons on weed identification. They weeded once a month.

Vector Control

In areas where water stands for longer than 72 hours, mosquito breeding is an issue although this has not been locally documented in swales. Under warm conditions, mosquito eggs take 24-48 hours to hatch and another several days to develop into pupae. Most local swales are reported to drain well within a 48-hour period. The *LA County LID Standards Manual* states that minimum infiltration rate for swales should be 0.5 inches per hour. Some city requirements state that water shall not stand for more than 48 hours but given infiltration rates in the Chino Basin, vector breeding should not be a concern.

Conclusion

These limitations highlight the need for local research of soil type and pollutant concentration from the time of installation onward. The local studies cited here examine runoff from streets and parking lots where pollutant concentrations are much higher than rainwater collected on rooftops. On-site stormwater capture from rooftops, walkways, and impervious patios may present a solution to avoiding these uncertainties of runoff collected from the street. As shown by the Elmer Avenue Retrofit, residents who were given the *Elmer Avenue Maintenance Manual* on how to take care of their swales assumed these maintenance responsibilities.

Capital and Long-term Costs

Capital Construction Costs

The Caltrans study cited bioinfiltration swales as the least expensive and most effective BMP device in reducing sediment and heavy metals. The average cost of these was $57,818. The City of Ventura's green street matrix lists vegetated swales as among the most expensive though still most effective LID BMP. Costs could not be found for Ventura's swales, however these differences are likely explained by costs of scale. Caltrans' BMPs were sited on large parcels of state-owned land where no right-of-way purchases were necessary. The vegetated swales in the City of Ventura required relocation of underground utilities and removal of parking spaces where the parkway was widened into the street.

The Elmer Avenue Retrofit cost $1.8 million to drain a 40-acre watershed, an estimated $0.6 million more than a conventional storm drain system. With 24 houses converting their parkway into a swale, the cost per property was $75,000. Headed by an architectural engineering firm, this project required asphalt street paving, concrete side walk installation, hydrodynamic separator filters, and several underground infiltration galleries that collect excess runoff. Primary funding was provided through grants from the US Bureau of Reclamation and CA Department of Water Resources while match funding was provided by many other departments within the city and county of LA.

Figure 17. This drought tolerant landscape installation by Jonescape includes a swale and cost approximately $4000 in 2013. Photo by Jonescape, Inc., a contracter located in Montclair, CA

The actual materials required to construct a swale are much less costly. A parcel-level swale that collects on-site runoff from a gutter downspout or rain barrel overflow, rather than from the curb, costs much less to construct. The Chino Basin sits on top of porous alluvial soil. Swales on non-porous or high clay soils require soil replacement to ensure proper drainage rates, increasing the price of a swale. In areas on a property where natural drainage occurs, excavation is less necessary and could be achieved by hand. Where larger quantities of soil excavation are required, renting earth-moving equipment may be necessary.

Value of Water Captured

The low cost of imported water compared to the price of constructing vegetated swales installed by a single agency has negated any monetary benefit of groundwater recharge. In a study that measured the *Costs and Benefits of the LA Watershed Augmentation Study Sites*, the capital and maintenance cost of a swale-type BMP was divided by the product of the average annual acre-foot infiltrated and the average 25-year lifetime of a BMP device. Four of the five sites with small-scale swales had costs vastly exceeding the value of water captured. For three of these sites, the cost per acre-foot of infiltrated water was approximately $4000. The site with benefits exceeding the costs was a larger-scale commercial installation. "The study concluded that BMPs with a capacity to treat all runoff from a parcel is too costly for the typical rainfall patterns (0.75" per storm) of Los Angeles." This study did not quantify the value of pollutant removal from infiltrated water and since the time of the study, imported rates have doubled.

Figure 18. A recently converted landscape in Santa Barbara capturing stormwater. (Project/photo credit: Wilson Environmental Contracting, Inc.)

The Council for Watershed Health conducted the Stormwater Recharge Feasibility Study for the Water Replenishment District of Southern California in 2012 and stated that LID stormwater capture costs exceeded imported water costs and that these were unfeasible for a single agency to install. Because vegetated swales provide several multi-party benefits, the study suggested funding occur through partnerships.

Appendix D of the *2013 Recharge Master Plan Update* (RMPU) by the Chino Basin Watermaster (CBWM) noted that stormwater recharge projects with costs under $600 per acre-foot of recharged water are prioritized. The average cost of stormwater recharge in the Chino Basin post-2014 is $380 per acre-foot, likely due to the use of large-scale and long-lasting percolation basins. For reference, in January 2018 imported water from the Metropolitan Water District was priced at $1015 per acre-foot of treated water and $692 per acre-foot of untreated water.

Conclusion

From a funding perspective, vegetated swales are not currently economically feasible when paid for by a single agency. This is due to two factors: the modest price of imported water compared to the amount captured by a vegetated swale during an average rain event, and the economies of scale of large-scale percolation basins. This is subject to change in the future as these projects' costs relative to the cost of imported water and large-scale recharge decrease. Parcel-level swales in residential landscapes could take a decade before their cost of installation equals the value of water infiltrated. The maintenance requirements detailed in the previous section are also important to note when considering the cost of installation. Where a single agency is responsible for maintaining swales, costs of labor must be considered.

Current Stormwater Recharge in the Chino Basin

Both CBWM and IEUA are primarily interested in more centralized approaches to stormwater capture. The CBWM advocates for improvements to large scale basins to allow for large volumes of capture, easier maintenance, and simplified monitoring. The IEUA is largely focusing on increasing groundwater supplies through tertiary-treated wastewater recycling. From the IEUA's perspective, the main hindrance with percolation basins is the lack of delayed volume capture during flood events. If installed in great enough quantities for a given area of runoff, vegetated swales could help by providing a slower release of water during and after a rain event.

The *2013 RMPU* provides information on water supplies and demands, groundwater levels and projected changes, replenishment sources, existing recharge facilities and their capacities, and suggested operational changes in stormwater recharge in the Chino Basin.

Table 2: Current and projected water supplies and demands in the Chino Basin. (CBWM 2013 RMPU)

	Current	**2035 Projection**
Total Water Demand	309,000 AFY	417,000 AFY
Groundwater Production	159,000 AFY	190,000 AFY
Recycled Water Direct Reuse	14,000 AFY	41,000 AFY
Imported MWD Water	57,000 AFY	106,000 AFY
Aquifer Safe Yield	140,000 AFY	129,000 AFY

These RMPUs are completed every five years; however, the 2018 RMPU was not completed at the time this report was prepared. Table D-1 on page 241 of the RMPU compares proposed stormwater capture upgrades to their annualized costs, acre-feet per year captured, and recharge unit cost in acre-feet. The least expensive projects for the highest volume capture are mostly capital improvements to install new basins, deepen existing basins, and automate inflow gates. Nearly all projects listed had capital costs of several million dollars. Analyses of residential scale capture projects were not included here. Project 16 on this table lists the only bioswale studied. This *Ontario Bioswale Project* captures an estimated 8 acre-feet per year at a total cost of $650,000, however no recharge unit cost was included on this project.

The CBWM 2016-17 *Annual Report* is subtitled, "Reducing Dependence on Imported Water" although detailed plans to implement this are lacking. This document highlights the need for a storage management plan since groundwater total storage levels are declining. At current rates, total storage in the basin will drop below the Operational Storage Requirement of 5.3 MAF by 2041. It calls for an unquantified decrease in imported water purchases. CBWM is also focusing on dry-year yield in which MWD stores imported water in the ground for removal at a later date.

Conclusion

A declining safe yield and a significant projected increase in imported water demands illustrates the urgency of the problem. Local water supplies are dwindling and water security needs to be ensured in a sustainable, economically reasonable manner. The *Climate Change Analysis for the Santa Ana River Watershed* anticipates higher temperatures, less snowpack, more flooding and less natural groundwater recharge in the region as a result of development. With increased regional climate uncertainty and exacerbated drought-deluge cycles, local water capture and storage is important now more than ever. Parcel-level swales have not been studied as a means of increasing stormwater capture for the Chino Basin's water utilities. This is likely due to the increased costs of construction and maintenance of parcel-level swales installed by a single agency. Existing percolation basins enable consolidated operations and maintenance schedules and improvements to these are the focus of stormwater capture for the Chino Basin's utilities. In terms of augmenting groundwater supplies, such utilities are largely directing their efforts towards large-scale approaches.

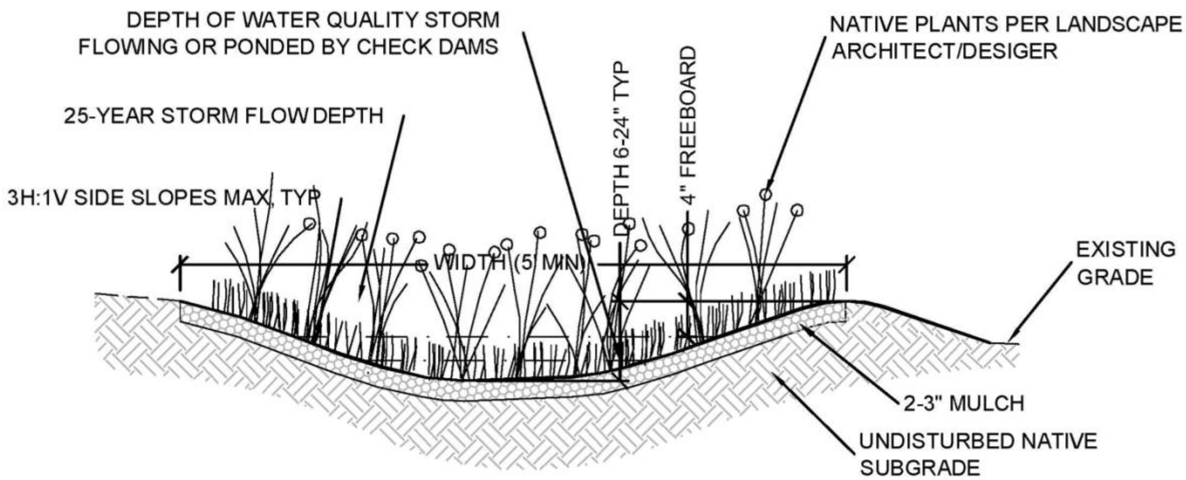


Figure 19. A peer-reviewed detail of a vegetated swale for planning purposes. (OSU Extension Service)

Fostering Resilience through Public Engagement

One of the CBWCD's three objectives is public education about water conservation and local watershed knowledge. Public awareness of stormwater as a resource is crucial to helping community members understand that the water they drink is stored under their feet after it falls from the sky. While vegetated swales replicate a natural process, they are no less a part of the water conveyance infrastructure than pipelines, canals, and percolation basins. Citing swales within the residential, business, or park landscape calls attention to their purpose, much like a rain barrel, and brings the topic of water conservation to the passer-by.

While small-scale vegetated swales are currently too costly for an agency to fund and potential maintenance and longevity limitations exist, there is still a need for residents to understand their role in the built watershed. Informed residents can act as stewards and expedite the spread of local knowledge, leading to a collective understanding of local problems and solutions. Teaching community members ways in which they can reduce their environmental footprint helps the region become more responsive and resilient during the next drought.

Figure 20. A newly planted swale on Elmer Avenue. (Project/photo credit: Wilson Environmental Contracting, Inc.)

Properly implemented, vegetated swales could serve this educational function. Every property functions as a watershed. Sourced from rain, water collects on rooftops, follows the path of least resistance to the ground, and enters the storm drain. After this point, the water itself and the pollutants it collects are out of sight and out of mind. For property owners already interested in re-landscaping, swales could provide not only added beauty, but also a means of on-site capture—a landscape version of the rain barrel.

Because the *Elmer Avenue Retrofit* hinged upon collaborative efforts between public utilities and residential property owners, informed residents were crucial to its installation and maintenance successes. In the service area of CBWCD, informed residents could act in the same manner. Litter removal and plant maintenance were previously mentioned as potential long-term concerns, but lessons provided to property owners on Elmer Avenue by the Council for Watershed Health taught them how to care for these swales. The following information was found in a 2011 survey:

- 67% would consider purchasing a rain barrel if their neighbors had one
- 100% of respondents agreed that rain falling on local homes can be captured and used to supply their community with water, versus 60% in 2006
- 80% felt that individuals can help reduce the amount of polluted runoff and add to local water supplies
- 92% of respondents felt that the hands-on training, maintenance manual, and project contacts were somewhat or very effective.
- 69% of respondents were subsequently familiar with the term "infiltration" and 85% were familiar with the term "runoff"

Conclusion

Despite a low response rate for the survey, these results are nonetheless striking. When residents take ownership of the effort to reduce runoff from their property, they likely examine and understand other aspects of their water use. Seeing a neighbor with a rain barrel, vegetated swale, or a water wise landscape may influence their next landscaping decision. Perhaps it would induce a change in their daily routine towards conserving water. Creating a participatory base of residents who take pride in their engagement with the community is critical for fostering a cultural shift in daily water consumption.

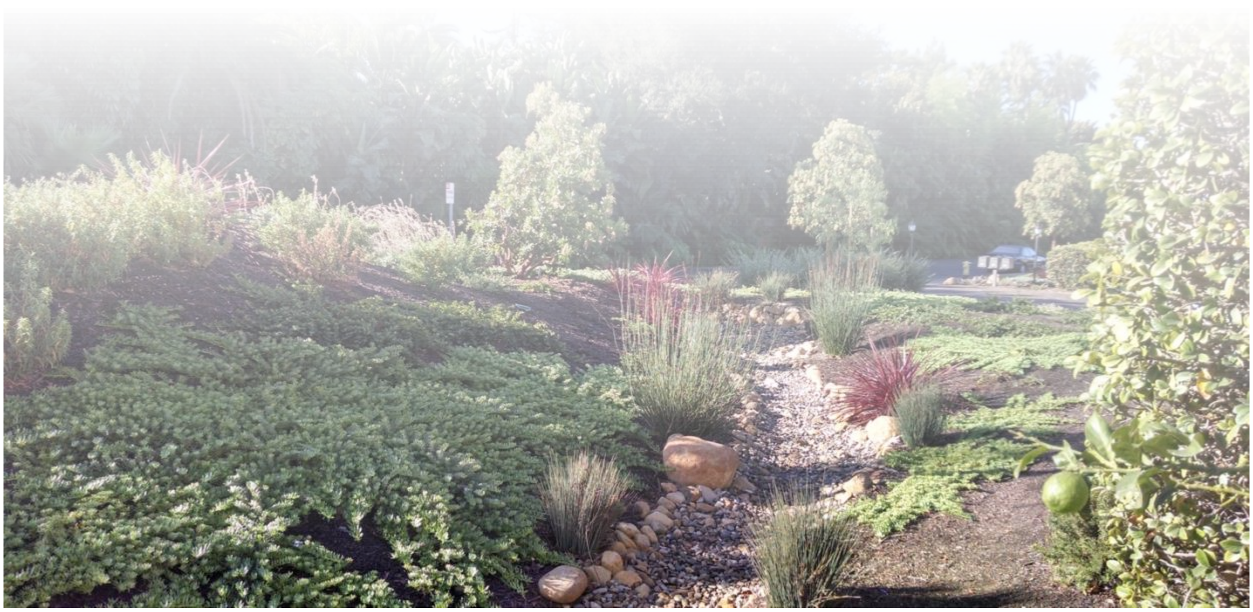


Figure 21. (Project/photo credit: Wilson Environmental Contracting, Inc.)

Possibilities for Installations

An effective approach to initiating a cultural change towards water conservation while avoiding the uncertainties of vegetated swales is still possible through these devices. The uncertainties of pollutant accumulation and groundwater contamination potential are grounded in studies that examine captured water from the street, where pollutant levels are much higher than an average residential property. The *National Academies Press* study on the risks, costs, and benefits of stormwater infiltration states that to avoid these concerns, swales should be sourced in areas with the least contaminated runoff. It then lists roofs, walkways, and little used driveways as possibilities for collection areas. What rain barrels do not capture, vegetated swales could.

The vegetated swale could be a tool through which CBWCD educates residents about local runoff capture. In their outreach program, CBWCD already includes garden-planning services, irrigation assessments, and landscape evaluations; and their demonstration garden includes several examples of swale designs. Throughout the landscape design appointments, vegetated swales could serve as a talking point for reducing both runoff volume and monthly landscape water bills.

Figure 22. This vegetated swale in the parkway receives water from the street, but can easily be adapted to accept rooftop runoff. (Clarion Associates)

A list of frequently asked questions posted on the CBWCD website would make this knowledge of vegetated swales more accessible to a greater number of people. Recommended questions are provided in Appendix B and are available for use at CBWCD's discretion.

Conclusion

Vegetated swales are an effective natural method of reducing pollutant and sediment levels in stormwater. A swale's ability to capture pollutants presents concerns about their longevity as pollutant concentrations may reach hazardous levels depending on the quality of water they receive. In high pollutant areas, such as parking lots and streets, regular testing is recommended to ensure pollutants are not affecting groundwater, and to measure pollutant concentrations in soils.

Swales also require some maintenance to prune vegetation, add mulch, and remove sediment, weeds, and trash. When paid for by a single agency, swales are not currently economically feasible due to the cost of installation and the modest price of imported water compared to the value of stormwater they capture.

As California's increasingly erratic climate cycles from drought to deluge, and as imported water supplies become less reliable with increasing temperatures and reduced snowpack, local water security and resilience is critical. When used to capture runoff from rooftops, patios, and driveways, parcel-level vegetated swales avoid the uncertainties of pollutant accumulation from streets, reduce runoff, and reduce the cost of outdoor watering. These can be easily integrated into existing and new landscapes. Increasing their presence could further advance public awareness that water conservation can easily be incorporated into daily life while providing both individual and community-wide benefits. Increasing public awareness about this facet of low impact development can also encourage an ideological shift in the California Dream—one that recognizes the value of a landscape that captures and conserves, rather than consumes excess water.

Figure 23. A drought-tolerant and stormwater-capturing front yard at a residence in Riverside, CA. (www.pacifichorticulture.org)

Appendix A: Annotated Studies

Achievements in Conservation, Recycling and Groundwater Recharge (2018): Pages 11-15 of this report by MWD explain the ways in which MWD marketed water conservation to its diverse rate payer base. The results of its focus groups to better understand changing perceptions of conservation showed “a strong willingness of many Southern Californians to permanently change their water use because it ‘is the right thing to do’ regardless of drought conditions.” http://www.mwdh2o.com/PDF_About_Your_Water/2.1.1_Regional_Progress_ReportSB60.pdf

Caltrans BMP Retrofit Pilot Program (2004): This evaluated 12 BMPs including sand filters, wet basins, oil-water separators, multi chambered treatment trains and bioinfiltration swales. The 6 grass-lined bioinfiltration swales were among the least expensive and best performing BMPs in reducing heavy metals and sediment. These were large-scale swales sited alongside highways already under Caltrans jurisdiction and the did not require right-of-way access or permitting. http://www.dot.ca.gov/hq/oppd/stormwtr/Studies/BMP-Retro-fit-Report.pdf

City of Ventura Residential Parkway Bioswale Permits: This page on the city’s website provides information on Ventura’s process for permitting curb cuts for parkway swales. It contains links to engineering diagrams of curb cut and swale design, planting requirements, and permit applications. https://www.cityofventura.ca.gov/397/Residential-Parkway-Bioswale-Permits

Chino Basin Stormwater Resources Plan (2016): This report by the IEUA provides information about current recharge practices and planning in the Chino Basin. Section 2.3 titled Stormwater Resource Planning notes that recharging stormwater and dry-weather runoff improves water quality in the Santa Ana River by reducing metal, nutrient, and pathogen concentrations. https://18x37n2ovtbb3434n48jhbs1-wpengine.netdna-ssl.com/wp-content/uploads/2016/05/Chino-Basin-SWRP-20160513.pdf

Chino Basin Watermaster Annual Report (2017): This document highlights the need for a storage management plan since groundwater total storage levels are declining. At current rates, total storage in the basin will drop below the Operational Storage Requirement of 5.3 MAF by 2041, as shown by graph on page 3. This briefly explains their dry-year yield storage program in which the CBWM, IEUA, and TVMWD allow MWD to place up to 25,000 acre-feet of water per year into the aquifer for use at a later date. This report also explains their groundwater monitoring programs and stormwater recharge program. http://www.cbwm.org/docs/annualrep/40th Annual Report.pdf

Climate Change Analysis for the Santa Ana River Watershed (2013): This report by the US Bureau of Reclamation evaluates the implications of climate change, increased energy demand, and future water quality and supply needs of this watershed. One goal of the study includes ensuring a collaborative approach between all water stakeholders regarding watershed adaptation planning. It estimates decreases in precipitation, increases in average and extreme temperatures, significant decreases in April snowpack, increases in flood severity, and reductions in natural groundwater recharge. It is part of the Santa Ana Watershed Basin Study (Basin Study) for the Santa Ana Watershed Project Authority (SAWPA). https://www.usbr.gov/lc/socal/basinstudies/OWOWReferences/FinalReport/TM 1 Climate Change.pdf

Climate Change in the Los Angeles Region Project: This project by UCLA is a collaborative effort to study the impacts of climate change specifically in the LA region. This link contains many studies that model precipitation, snowpack, temperature, groundwater recharge, runoff, and weather events in the region. Research here suggests an increase in the extremes of drought and deluge cycles in California. http://research.atmos.ucla.edu/csrl/pub.html

Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices (2008): This review examined stormwater infiltration techniques and the subsequent fate of heavy-metals, organics, pathogens, suspended solids, nutrients, and salts. Because the potential for groundwater contamination is a function of soil makeup, contaminant type, and depth to groundwater, local research is always necessary. The review found that heavy metals are usually retained in the upper layers of soil but that soil replacement every decade could be necessary in preventing metals from saturating soils and traveling further down. Suspended solids are removed but thus accumulate and can reduce infiltration rates. Organic pollutants have high soil affinity and can biodegrade over time in soil but this depends on soil type and climate. https://www.pca.state.mn.us/sites/default/files/stormwater-r-weiss0608.pdf

Costs and Infiltration Benefits of the Watershed Augmentation Study Sites (2006): This examined five parcel-level infiltration BMP solutions of the LA Watershed Augmentation and found that four of five sites captured almost all runoff from large and small storms. Because large storms are relatively infrequent, “a large portion of the BMP capacities were rarely needed.” Because of this, costs of construction and maintenance “substantially exceeded the groundwater recharge benefits” at the four smaller sites. The site with the largest benefit-cost ratio was a larger commercial site. http://lasgrwc2.org/Files/document/271_UCR_LASGRWC_041806.pdf

Elmer Avenue Maintenance Manual (2010): This report was specifically written to inform residents participating in the Elmer Avenue Retrofit how to maintain their swales. It explains and provides checklists on watering, weeding, mulching, pruning, plant replacement, debris clearing, and trash pickup. It also provides information on rain barrels, permeable pavers, and trench drains which collect water at the bottom of a driveway. Included appendices provide photos of weeds and native plants for identification. A Spanish version could not be found as the links to it are currently broken. https://docs.wixstatic.com/ugd/ceb944_69b595c72b9f412b9aa0449798739375.pdf

Green Gardens Group (G3): This organization advocates a watershed approach to landscaping, demonstrating that every piece of property functions as a watershed. They demonstrate why it is important that such properties have healthy soil, rainwater capture devices, local climate appropriate plants, and efficient irrigation when it is required. https://greengardensgroup.com/watershed-approach-to-landscaping/

Green Infrastructure for Los Angeles, Addressing Urban Runoff and Water Supply Through Low Impact Development (2009): This report examines potential steps for instituting a city-wide low impact development program in LA. It provides examples of landscape, building, street-side, and site planning LID BMPs and illustrates the energy usage, water supply and water pollution benefits of these projects. http://www.environmentla.org/pdf/LID-Paper_4-1-09_530pm.pdf

Los Angeles Basin WAS Phase II Final Report (2005): This study examined concentrations of runoff-borne pollutants before and after infiltration at six parcel-level sites, four years after their construction. It found that within this time frame, heavy metals and total dissolved solids did not travel into groundwater. Industrial sites had higher concentrations of organic compounds and heavy metals in soils. The study concluded that no immediate impacts to groundwater quality exist with stormwater infiltration at the surface. http://lasgrwc2.org/Files/document/265_2005_WAS Phase II Final Report_2005.pdf

Los Angeles County LID Standards Manual (2009): This report provides design requirements, advantages, and limitations of 15 LID BMPs including vegetated swales, biorention devices, and infiltration basins. It contains site planning design requirements on minimum infiltration rates and slopes and also provides methods for calculating runoff volume for larger projects. http://planning.lacounty.gov/assets/upl/project/green_la-county-lid-manual.pdf

Los Angeles Watershed Augmentation Study (WAS): This project by the Council for Watershed Health has been studying the feasibility of stormwater capture in LA since 2009. Their website contains many studies about this project including the *Costs and Infiltration Benefits of the WAS Study Sites*, *Stormwater Recharge Feasibility and Pilot Project Development Study*, and *LA Basin WAS Phase II Final Report* listed in this appendix. http://lasgrwc2.org/dataandreference/Document.aspx?search=48

Oregon State University Extension Service: As part of an effort to encourage low impact development approaches to managing stormwater, this website provides free peer-reviewed diagrams that can serve as the basis for a project. They include plans of swales, drywells, rain gardens, filter strips, stormwater planters, and porous pavement. http://extension.oregonstate.edu/stormwater/standard-details

Plants for Vegetated Swales: This chart by Stopwaste provides a list of California Native plants suited for use in vegetated swales. It includes botanical and common names, height and spread specifications, and sun, soil, and water requirements. http://www.stopwaste.org/sites/default/files/Documents/Bay-Friendly Plant List_Swales.pdf

Santa Ana River Water Quality Health Study (2004): This study documented the path of water pollutants from tertiary treated wastewater into Orange County Water District's percolation basins and found that all heavy metals were below regulatory limits. This report contains comprehensive data on the underground movement of many pollutants within OCWD's service area.
http://www.nwri-usa.org/pdfs/SARWQHFinalReport.pdf

SoilWeb, UC Davis, Natural Resources Conservation Service: This interactive map allows the user to search for their soil profile to determine the composition of soil.
https://casoilresource.lawr.ucdavis.edu/gmap/

State of the Basin Report (2016): As part of the Chino Basin Optimum Management Program, this report provides much of the same information as the 2013 RMPU but in a more condensed format. It also includes historical precipitation charts, Santa Ana River base and storm flow charts, and a land use chart displaying the increase in urban impervious cover in comparison to agricultural and undeveloped land. It also contains historical streambed infiltration graphs showing the elimination of percolation from the lining of creeks, and the subsequent increase in stormwater capture from constructing basins in 2001. Page 23 provides annual recharge volumes of stormwater, imported water, and recycled water from 2000 to 2016. Pages 42-66 provide maps of groundwater quality monitoring wells and subsequent values for primary and secondary pollutants at specific locations.
https://cwc.ca.gov/WISPDocs/IEUA_2016 State of the Basin Report.pdf

Stormwater Capture potential in Urban and Suburban California (2014): This report by the Pacific Institute estimates that stormwater capture on new and redevelopment sites in urbanized Southern California and the San Francisco Bay has the potential to increase water supplies by 405,000 – 603,000 acre-ft.
https://www.pacinst.org/wp-content/uploads/2014/06/ca-water-stormwater.pdf

Stormwater Recharge Feasibility and Pilot Project Development Study, LAWAS (2012): Examined stormwater recharge projects and their potential to improve water quality. It found that 10% of the 270,000 acres within the Water Replenishment District of Southern California service area could recharge nearly 17,000 AFY. A cost-benefit analysis concluded that these distributed projects are too costly for a single water agency to construct on their own and hence advocates for multi-party funding strategies. http://lasgrwc2.org/Files/document/785_1208020_SWRechargeFeasibility and PPDS_FinalReport.pdf

Sustainable Infrastructure: The Elmer Avenue Neighborhood Retrofit (2012): Describes the Elmer Avenue Retrofit project with illustrated diagrams and photographs. Provides graphs revealing significant total copper, lead and suspended solids removal and states that 23 AF of stormwater entered the underground galleries from April 2010 to December 2011. This report describes plant survival rate, weed cover, trash accumulation, sediment deposition and provide survey results from residents involved with the project. http://lasgrwc2.org/Files/document/793_2012 Belden.pdf

Using Graywater and Stormwater to Enhance Local Water Supplies, An Assessment of Risks, Costs, and Benefits (2016): This report by the National Academies Press assesses current national trends in stormwater and greywater use across multiple scales. While highlights sources of contamination in stormwater that are consistent with other studies in this appendix, it also includes information about potential human health and environmental risks.
https://www.nap.edu/read/21866/chapter/1

2013 Amendment to the 2010 RMPU: This report for the Chino Basin Watermaster provides extensive data about groundwater storage and production, an inventory of existing recharge facilities and their capabilities, monitoring programs, and recharge options. http://www.cbwm.org/docs/engdocs/2013 Amendment to the 2010 RMPU/2013 Amendment to the 2010 RMPU – Sections 1 through 8.pdf

2013 Amendment to the 2010 RMPU, Chapter 4: Inventory of Existing Recharge Facilities and Their Capabilities (2013): This chapter of the RMPU illustrates stormwater, imported water and recycled water recharge quantities. It contains suggestions for increasing percolation rates of basins and describes ways in which the Chino Basin's facilities can increase large-scale stormwater capture.
http://www.cbwm.org/FTP/Recharge Investigations and Projects Committee (RIPCom)/CB RMPU Steering Committee/2013 RMPUA/RMPU Sections/Red line Sections 1-4/20130903 Rechage Master Plan - Section4.pdf

2013 Amendment to the 2010 RMPU Appendices: Appendix D of this RMPU, beginning on page 234, provides the following tables:

Table D-1 *Project Data for Yield Enhancement Projects* contains a detailed characterization of all the yield enhancement projects that were analyzed in detail.

Table D-2 *Summary of Unit Costs* contains the unit costs that were developed jointly by CBWM and IEUA and that were subsequently used to estimate the capital cost of each project that passed the initial screening cost of $1,500 per acre-ft.

Table D-3a through D-19 contain cost opinions for all the 2013 RMPU yield enhancement projects that passed the initial screening cost of $1,500 per acre-ft.

Table D-20 through D-24 contains the rankings of the yield enhancement projects using evaluated using three thresholds: a marginal unit cost less than $600 per acre-ft, a melded unit cost less than $600 per acre-ft, and a melded unit cost less than $612 per acre-ft. The three unit cost thresholds were analyzed with and without the excavation discount.

http://www.cbwm.org/docs/engdocs/2013 Amendment to the 2010 RMPU/2013 Amendment to the 2010 RPMU -- Appendices.pdf

Appendix B: Frequently Asked Questions

1. What is a vegetated swale?
    a. A vegetated swale is essentially a constructed streambed or shallow channel that collects runoff and allows it to absorb into the soil. This absorption process is called infiltration. Because it has a natural bottom, swales act as a sponge and can reduce the peak volume and speed of runoff, thereby reducing erosion. A swale is lined with plants and mulch, both of which slow down and filter runoff, allowing water to infiltrate into the ground.

2. Why are there so many terms for swales?
    a. Vegetated swales, bioswales, infiltration swales, and bioinfiltration swales are some of the terms used to label different types of swales. While they all filter stormwater and promote infiltration, each swale serves a slightly different function. Infiltration and bioinfiltration swales are still designed to infiltrate stormwater, but typically have less of an emphasis on plants, or vegetation. Bioswales and vegetated swales are often used interchangeably, but some sources suggest bioswales encourage water to spend more time pooled up in ponds, while vegetated swales are meant to moving it.

3. What is infiltration?
    a. Infiltration is the movement of water into the soil. This occurs at the surface where soil first absorbs water. While commonly used interchangeably, infiltration and percolation are different. Percolation is the process by which water in the ground, after it has infiltrated, moves further downward until it reaches groundwater.

4. Why are vegetated swales used?
    a. Vegetated swales are an increasingly popular method of reducing the amount of water that runs off a property. By reducing runoff at its source (any impervious surface) and redirecting it, swales increase local groundwater supplies and decrease reliance on imported water. They are used in Los Angeles' low impact development (LID) ordinance to help restore the natural hydrologic (water movement) conditions that existed before development. Historically in the Chino Basin region, precipitation fell on the San Gabriel Mountains to the north, accumulated in floodplains and flowed down creeks into valley before percolating down into the groundwater. This process still occurs, though at a slower rate since much of the region is impervious. During storms, our rooftops act as miniature mountains, but runoff is often sent down the storm drain. Vegetated swales allow this runoff to collect and percolate once more into the ground, all the while creating a beautiful landscape. The Green Gardens Group (G3) provides landscaping guidelines and visual descriptions of how every piece of property functions like a miniature watershed. More information on this can be found here: https://greengardensgroup.com/watershed-approach-to-landscaping/

5. Why are impervious surfaces detrimental?
    a. Concrete, asphalt, and rooftops are the most abundant examples of impervious surfaces. Water cannot permeate an impervious surface. Instead, it runs off as lost water during a storm or as nuisance flow from runoff in dry months. In the Chino Basin region, 60% of land is now impervious, compared to 10% in 1960.
    b. Often this runoff collects trash that ends up in either the percolation basins that CBWCD helps manage or the Santa Ana River. Runoff also collects pollutants that accumulate on streets from vehicles. During large storms, these pollutants, combined with bacteria from wastewater treatment overflows, can result in coastal water contamination and beach closures.
    c. Concrete and asphalt absorb heat throughout the day and release it after the sun sets, heating nighttime air which is then heated even more the next day. This is called the urban heat island effect and it is worsened in the Inland Empire where temperature inversion layers during the summer trap warm air. Converting a previously impervious surface to natural landscaping helps reduce local temperatures since soil and plants remain much cooler in the sun than impervious surfaces.

6. How do vegetated swales help me?
    a. Up to 40 percent of our water comes from under our feet as groundwater. Groundwater does not evaporate and keeps us afloat, literally. Over pumping of groundwater causes subsidence which occurs when land sinks and becomes compressed. This permanently eliminates soil’s ability to hold groundwater. By allowing water to infiltrate, swales increase groundwater supplies, providing you with a more secure source of local water, especially during droughts.
    b. Because they are planted with drought-tolerant plants that typically do not require watering after they are established, swales reduce your monthly watering bill and add a beautifying element to your landscape.

7. Can I install these myself?
    a. Absolutely. The CBWCD’s Water Wise Demonstration Garden contains several examples of vegetated swales and a visit here can help you visualize how to properly create one. To work effectively, swales need a source of water to begin with. This can come from a rain barrel overflow, a gutter downspout, or a trench drain at the bottom of a driveway. From here, they act like a stream by carrying water downward and away from a building. Simply placing rocks on top of soil, however, will not direct water. It may be necessary to excavate soil 1 or 2 feet deep along the length of a swale to make it effective in capturing runoff. Remember to call your local utilities if you are unsure of underground pipe locations. In the Chino Basin region, soils are porous meaning that they allow water to infiltrate quickly, so mosquito breeding is not an issue. If you live outside of the Chino Basin, this interactive map will help you to find the profile of soil around you: https://casoilresource.lawr.ucdavis.edu/gmap/

8. What kind of plants work best in a swale?
    a. Many plants native to California are excellent at enduring dry periods (typically between May and November) that are punctuated by rainstorms. This document from *Stopwaste*, a public agency in Alameda County, provides a list of California native plants that are well-suited for vegetated swales. It includes sunlight, shade, height, and initial watering requirements as well. http://www.stopwaste.org/sites/default/files/Documents/Bay-Friendly Plant List_Swales.pdf

9. Where can I purchase native plants?
    a. The California Native Plant Society website contains an interactive map showing native plant nurseries nearest to you. http://www.calscape.org/plant_nursery.php

10. Do swales require maintenance?
    a. Yes. To keep them functioning, swales require re-mulching typically every 1-2 years or when mulch becomes less than about 3 inches thick. A thick layer of mulch prevents widespread weed growth, absorbs potential pollutants, and lowers your water bill by reducing evaporation. Monthly weeding may be necessary and leaves should be removed from the swale when they build up. This manual from the Elmer Avenue Retrofit, a neighborhood-wide swale installation in Sun Valley, CA, can help you identify weeds and understand maintenance needs in more depth. https://docs.wixstatic.com/ugd/ceb944_69b595c72b9f412b9aa0449798739375.pdf

11. Are there any concerns with vegetated swales?
    a. Because they work so well at filtering stormwater, vegetated swales that collect highly polluted water from heavily trafficked streets or industrial yards have the potential to become saturated pollutants over time. Pollutants found in this runoff include heavy metals, gasoline, diesel, oils, and fertilizers. Local studies have shown that these pollutants do not affect groundwater quality, but more studies are needed to determine if this occurs over a decade or longer. Swales that become saturated with pollutants require soil replacement and responsible disposal. Swales that collect water from your rooftop, patio, or cleaned driveway collect far lower concentrations of pollutants and should not be of concern.